To my wife and colleague Fadwa.
Without her constant and passionate encouragement,
this book would never have been written.

Artifact Classification

A Conceptual and Methodological Approach

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Preface

This book developed out of research that has appeared in numerous publications and a seminar on archaeological classification that I have been teaching at UCLA for the past several years. My interest in archaeological classification began during the shift I made from mathematics, my area of formal education, to anthropology, my professional area. My interest in archaeology started while in mathematics when I had the opportunity to work at the Upper Paleolithic, open-air site of Solvieux in the Perigord region in France. The site had already been partially excavated by Jean Gaussen and I was part of the first group that began what were to become a series of excavations undertaken by my colleague James Sackett.

Excavating the lithic tools and materials left behind by our ancestors thousands of years ago left permanent imprints on my outlook on humankind. People not all that different from us had lived at that location, raised families, searched for food, and enjoyed themselves in the peaceful beauty of the Isle Valley where the site was located. As part of their life, they had made these incredible lithic tools we were uncovering in such extraordinary abundance. Who were they? What was their daily life like? What were their thoughts about the present and the future? Of course, we can never fully answer questions like these and they continue to be the subject of debate ever since my days of excavation in the late 1960s, when the "New Archaeology" was in full bloom with its enthusiasm for what we might be able to learn about our ancestors (and ourselves) if we had the right analytical methods and dared to seek novel answers to difficult questions. Some of those methods and some of those questions were ones where the rigor of mathematical thinking could be usefully brought to bear.

The following summer, I had the good fortune to work with Lewis and Sally Binford, first at the Middle Paleolithic site of Combe Grenal and then at the laboratory in Bordeaux that housed the archaeological collections of François Bordes and Denise de Sonneville-Bordes. At Combe Grenal, we surveyed the cave site and its immediate surroundings to make clearer its topographical setting. Other kinds of questions came to mind since this was a "cave" site and had rich faunal (as well as extensive lithic) remains housed in the Bordeaux laboratory. Surveying was also a time for speculation—and Lewis Binford was good at speculation! For someone coming out of mathematics, it was a marvelous experience to hear him expound on his ideas about the inhabitants of the cave sites, the tools they made, and how they may have moved about in the environment with its many hills and valleys through the year in pursuit of food—formative ideas that later figured prominently in his publications.

When we left Combe Grenal for Bordeaux, the laboratory work gave me my first experience of the potential for using statistical methods to address substantive archaeological questions. In the laboratory, we had the site plans with the location of every item recovered by the excavations undertaken by the Bordes. Little of this had appeared in their publications and we had the opportunity to relate the physical structure of the cave to the location of faunal and lithic material—a task that today would be taken for granted and would hardly justify a footnote in a site report as a method. But this was the 1960s and even simple statistical measures of the spatial structure of an archaeological assemblage were not yet common.

Binford had given me the task of determining if there might be spatial structure within one of the excavation layers at Combe Grenal and if so, what information about the differential use of space could be inferred. Not surprisingly, distinct subareas within the overall spatial distribution of the tools could be statistically distinguished based on a method for testing the randomness of objects distributed over a bounded area that I developed and later used in introductory courses in statistics that I taught in the Anthropology Department at UCLA. François Bordes had characterized assemblages, taken as a whole, with cumulative frequency plots. I did the same for the subareas I had distinguished within a level of the assemblage and found as great a difference in the cumulative plots between subareas within a single level as Bordes had found between assemblages. Suddenly, the problem of heterogeneity in a data set became very real. The summary plot for an assemblage as a whole could not be taken as an index for the assemblage if it was, in fact, composed of distinct subareas—each with its own characteristic set of artifacts.

I had stumbled upon a statistical problem that I later discussed in detail in several publications (Read 1987, 1989a, 1989b). The basic idea is that summary measures made over a heterogeneous data set may be descriptively accurate yet fail to provide information that directly relates to the processes that underlie the patterning in the data underlying the summary measures. Bordes had made descriptively accurate summaries with his cumulative frequency graphs, but these summaries can be misleading when made over nonhomogeneous assemblages, thus raising

a question: does a cumulative frequency graph for the assemblage as a whole better characterize the site than the ensemble of cumulative frequency graphs constructed for each distinct subarea within the assemblage? If the latter, as appeared to be the case, then the summary graphs can lead to misleading interpretations. But these were ideas to be worked out later: the summer ended and I returned to UCLA to finish my dissertation in mathematics, "On (J, M, m)-extensions of Boolean Algebras," which subsequently published in the Pacific Journal of Mathematics (Read 1974a).

While finishing my dissertation, I began to explore the possibility of making a professional change from mathematics to anthropology, motivated partly by my interest in archaeology and partly by my interest in integrating mathematical thinking with theories regarding the nature of human societies. Anthropology was the natural area to combine these interests, especially since there was a strong push within anthropology in the 1960s for incorporating both statistical analysis and mathematical modeling as part of the mix of methods that could be used to represent the theoretical concepts and ideas being developed about the cultural basis for the social organization of societies. I was invited to join the UCLA Department of Anthropology as a faculty member beginning in fall 1970. Shortly thereafter, I was able to continue my interest in archaeology through becoming co-principal investigator (with Fred Plog as principal investigator) on the Chevelon Archaeological Research Project. When the initial one-year NSF grant was renewed, our colleague James Hill joined us as an additional co-principal investigator.

From these three research episodes, I have come away with a longstanding interest in archaeology as providing a window on how—historically and evolutionarily—we came to be what we are today, both biologically and culturally. I also began to identify two central questions that needed to be addressed as part of archaeological analytical methods. One had to do with the role of typologies as a basis for making evident the dimensions that were relevant to the makers and users of the objects we recover and refer to as artifacts. The questions I pondered at the open-air site of Solvieux related to the activities of the inhabitants of the site as they lived out their lives in that locality some thirty thousand years ago. To address these questions, even if we cannot fully answer them, we must look at the objects they made and left behind from the perspective of distinctions they had made regarding the lithics tools they had produced. What are the distinctions they made during the production of their lithics and how are these differences patterned through time and space?

Intellectually, this led me to the ideas of Irving Rouse, for this was the same kind of question that concerned him about the Fort Liberté artifacts from Haiti (Rouse 1939). What we call a "type" must be based

on the properties and distinctions that the makers and users shared collectively as part of their cultural milieu—that is, on what he called modes as opposed to attributes. This distinction had, and still has, profound implications for how we measure and analyze artifacts. Achieving the goals of archaeology as a scientific discipline aimed at explicating our complex interactions—both with the material world and our culturally constructed social world—depends on our ability to uncover the dimensions along which material objects are constructed, thereby giving us insights into what the technological, social, and cultural aspects of the material objects uncovered by the archaeologist can reveal about past societies.

A second, and related, question arose from my Combe Grenal experience. What methods can we use for dissecting an initially heterogeneous data set into subsets homogeneous with respect to the dimensions relevant to the production and use of artifacts? Quantitative methods such as numerical taxonomy and clustering algorithms were being developed in other disciplines and appeared to be what was needed to convert the construction of a typology from an intuitive, often individualistic enterprise into an objective, replicable representation based on similarity and dissimilarity among artifacts. However, from a mathematical viewpoint, one critical piece was missing. The methods being developed did not—and still do not—have a rigorous definition for what constitutes a cluster in a distribution of points in an n-dimensional measurement space. The often-cited criterion that clusters should be internally cohesive and externally isolated does not lead to a specific algorithm for distinguishing clusters.

At the suggestion of my archaeological colleagues at UCLA, in particular Fred Plog and James Hill, I began working on a mathematically defendable definition of a cluster based on locally identifiable characteristics of the distribution of points in an n-dimensional measurement space. While doing this work, I ran across an algorithm called Neighborhood Limited Classification (discussed in Christenson and Read 1977) that used essentially the same idea I was developing. I implemented the algorithm in a Fortran computer program and one of my graduate students, Andrew Christenson, applied the clustering algorithm to the 4VEN39 data set discussed in Chapter 8. We found that the clustering procedure failed to find any clustering in the data set when using the variables measured over the projectile points, but arrived at unambiguous dissection of the data set into two subgroups when outliers were removed from the data set and the clustering was based on principal components derived from the measured variables.

The paper we published (Christenson and Read 1977) has been both widely cited and sometimes misunderstood as either having results due

to our choice of a clustering algorithm, or that principal components should always be used in cluster analysis. Rather, our results made it evident that the problem of heterogeneity cannot be resolved through either a better definition of a cluster, the choice of an algorithm for finding clusters in the measurement space, or data reduction methods such as principal components. Clustering algorithms are typically biased toward clusters that do not have the taxonomic structure that typifies artifact production and therefore lead to groupings (and implied class definitions) that crosscut, in an unclear manner, the patterning imposed over the artifacts by their makers and user. No simple modification of algorithms would be sufficient, since the dissection has to be based on distinctions (modes, rather than attributes) not known in advance, as identification of these distinctions is one of the goals of the analysis. This leads to what I call the double bind problem (Read 1989b): the dissection must be based on criteria yet to be determined from the analysis of the data at hand. I concluded that the primary conceptual issue was not the definition of a cluster as an abstract concept, but on how to implement the concept of types that had been developed by Rouse and others that related material objects to both the material domain and the cultural and social milieu in which they were produced. How to resolve the double bind problem, then, became the primary methodological issue to be worked out.

I consider these two problems to be closely linked; analytical methods need to arise from our understanding, as archaeologists, of the dimensions along which patterning in the material domain is based. Statistical methods, whether univariate or multivariate, either assume homogeneity through the definition of a population (but what constitutes a homogeneous population in an archaeological context most often is not known in advance) or use methods (such as cluster analysis) whose assumptions do not concord with what we understand about the production and use of the material objects we refer to as artifacts. The double bind of first needing the patterning in the data to be obtained through analysis in order to define a homogeneous population as the basis for uncovering patterning in the aggregate has largely been ignored in the archaeological application of statistical methods and has not been addressed adequately in the statistical literature.

A solution to this double bind problem is not trivial. The methods I have developed and present in the following chapters utilize a recursive approach to resolve the double bind, but the motivation for using this approach requires that I first make explicit that the analytical methods that can help achieve the conceptual goals of archaeological analysis of artifacts must be faithful to our perception of artifacts viewed as objects embedded in the cultural milieu of the makers and users of the material

remains we recover through our excavations. To give this perspective a firm foundation, I begin the book with a review of the conceptual issues regarding artifact types and typologies worked out by Irving Rouse, John Brew, Alex Krieger, James Ford, Harry Colton, and others. I then examine how the attempt to give a quantitative foundation to what had been largely intuitively formed types and typologies began with two false starts: one through largely uncritical importation of numerical taxonomy methods into archaeology, and the other through a mistaken attempt to provide a statistical foundation for artifact types through statistical measures of variable association.

The primary proponents for these two methods have been Roy Hodson and Albert Spaulding, respectively. Together we participated in the week-long Kampsville Archeological Seminars on archaeological classification held under the auspices of Northwestern University in 1975 and 1977. Regrettably the disagreement between Hodson and Spaulding over these two methods caused the seminars to shift away from their goal of addressing why "numerous and extensive efforts to approach classification on a formal, quantitative basis have been disappointing" (Whallon and Brown 1982: xv) into a dispute between them over object grouping versus attribute association methods. The dispute was not helpful, since neither method is consonant with our understanding of the cultural, social and functional context of artifact production and use (see Chapters 3 and 4). The paper I wrote for the seminars, "Toward a Theory of Archaeological Classification (Read 1982)," addressed these issues and lays out the foundation for many of the ideas developed more fully in this book.

1

Introduction

Artifact Classification

Artifact classification is hardly new to archaeology. Artifact classification has played an important role in archaeological research as a means to organize artifact material ever since archaeology's inception as a field of study (see reviews by Klejn 1982; Dunnell 1986; Wylie 2002). At a pragmatic level, artifacts need to be organized in some manner to be able to deal with the sheer quantity of material remains recovered through excavation. Faced with tens or even hundreds of thousands of artifacts, ranging from small bits of lithic debitage and pottery sherds to complete lithic tools and pottery objects, some form of organization for these materials will be devised even if only in the form of a catalogue system for the retrieval of the artifacts of interest from the mass of material obtained through excavation. Pragmatic classifications of this kind may simply assign artifacts to classes whose definitions need no justification beyond their utility for organizing the material at hand.

Methodological Issues

From this perspective, artifact classification appears to have a simple methodology. Classes to which artifacts are to be assigned are determined and then artifacts are assigned to those classes based on the criteria for class inclusion (McKern 1939). Consider the usual division of artifacts based on the kinds of materials from which they are formed, such as pottery, lithics, bone, textile, and so on. Each kind of material can be the basis for a class definition and artifacts can then be assigned to a class in accordance with the material from which the artifact was formed. This widely used, implicit classification hardly needs comment as to its pragmatic utility. Yet as simple as it is, it already has within it a deeper set of issues that make the task of classification of objects that are a part

of material culture a complex matter. These issues involve fundamental questions relating to our understanding of human social and cultural systems, and the production of the material objects we refer to as artifacts, if the classification is to go beyond simply being a means to organize a disparate body of material (Krieger 1944; Hayden 1984) and provide insight into the "meaning of the myriad works of man" (Krieger 1944: 275).

The deeper set of issues and how they relate both conceptually and methodologically to archaeological classification of artifacts is central to the analytic methods developed in this book. We can make these issues evident by asking why classification by kind of material is so widely accepted as the first step in organizing a body of artifact material, either implicitly or explicitly (e.g., Garcia Cook 1967). Why the wide-spread use by archaeologists of these broad material categories? Is this simply a convenient, imposed order for the artifacts of concern to the archaeologist? If so, why not begin with more specific kinds of lithic material such as flint, obsidian, or basalt, or with the chemical characteristics of the clay from which pottery is made, or with the particular species of plant used in making baskets? Or from another perspective, why don't we begin with functional—rather than material—differences among artifacts?

Instead of using kind of raw material, we could form a classification by defining classes based on the function (or expected function) of an artifact, such as slicing and cutting, vessels for storage of liquid, material for making clothing, and so on. Were we to do so, we could then ask how these functional classes relate back to the material properties of artifacts. In answer to our question, we would find considerable concordance between our functional classification and a classification by kinds of materials. Vessels for storing liquids are seldom made from lithic material and artifacts used for slicing are not likely to be made from clay. This correspondence between material and function is not happenstance. Instead, it arises because of decisions that past makers and users made regarding what are appropriate artifacts for the tasks at hand and how this relates to the properties of raw materials.

Functional Constraints

The basis for the concordance is thus straightforward. Functional tasks depend upon physical characteristics of the artifact and these can be realized better in some materials than others. Making stone vessels for storage of liquids is not impossible but it takes substantially more labor to produce a vessel made from stone than a vessel made from clay. Or a projectile point made from clay will not have the physical characteristics needed for the point to penetrate and kill an animal. In brief, our initial classification by distinctive material categories reflects the fact

that artisans made artifacts from materials that provide effectively the physical properties necessary for the tasks at hand. The material categories we use for the preliminary sorting of artifacts also happen to be materials that have these physical characteristics. Had the artisans not made distinctions in the production and use of artifacts according to kind of material, then sorting of artifacts in this manner would simply be an imposed order and the distinctions we make would not relate to decisions they made when producing artifacts.

Constraints on class definitions arise when the classification is intended to go beyond just being an organizational device and should elucidate aspects relevant to the production and use of material objects. A classification aimed at determining classes of artifacts that sort sites in a region into a serial time sequence, for example, depends on forming classes that can be mapped faithfully onto calendrical time. This depends upon identifying time-dependent attributes whose occurrence on artifacts is independent of the geographical location within the region of interest. In contrast, a classification aimed at identifying patterns of interactions among the inhabitants of settlements in the same geographic region requires classes of artifacts with a space and time distribution pattern for the artifact classes that reflects aspects of that interaction pattern.

Cultural Constraints

In both of these examples, the classification is constrained by our wanting to identify aspects of the social and cultural system reflected in the production and use of the material objects. The underlying presumption of a social and cultural context for the production and use of material objects comes to the fore since ultimately we are not dealing with individual, physical objects, but with culturally framed conceptual systems that underlie the production and use of individual artifacts. The causal direction is, generally speaking, from concept to artifact in terms of production and use, whereas our analytical direction is from artifact to inference of the concepts that provide the patterning and order we discern in the artifact material we have excavated and brought forward for analysis. What we refer to as a "projectile point," for example, is our simplified way of referring to a complex of concepts and ideas that connect both the material and the ideational domain to the objects, and thereby to various contexts in which the objects may have been used. The material domain of artifacts includes the artisan's choice of raw material, techniques of flint knapping, functional constraints on the form of a point for its effective, intended use, and so on. Each of these relates to the ideational domain through conceptualizations that the makers

and users of artifacts may have had about what constitutes appropriate raw materials, different techniques that might be used in the production of an artifact, and so on.

Missing from our research methodology are analytical methods designed to be sensitive to the distinctions made by the artisans who produced the artifacts, and in concordance with the underlying processes that gave rise to the patterning we want to uncover through our analysis of the materials recovered from our excavations. As noted by Albert Ammerman in a review of the use of quantitative methods in archaeology, we need "methods that are better tailored to the nature of archaeological problems" (1992: 252; see also Kintigh 1987; Aldenderfer 1998). Analytical methods should not be formed in isolation from our understanding of the conceptual framework linking the ideational domain of shared concepts to the patterning that occurs at the phenomenological level of material objects, including how that patterning is distributed across space and through time. From this perspective, a typology is a special kind of classification consisting of types, where by a *type* we mean a class demonstrated to have cultural salience. By a *typology* we mean our organization of types in accordance with an underlying conceptual system (or systems) for the production of artifacts. In some cases, the arrangement may be intended to have an instrumental purpose such as dating of sites; more generally, it is a way to achieve the oft-stated goal of "archaeology as anthropology." A typology is thus a way to represent systematically the patterning imposed on artifact material by the makers and users that has subsequently been uncovered analytically by the archaeologist.

Determining ways to uncover a prior, existing order already imposed on the material objects we refer to as artifacts, which can be related to the social and cultural context in which the material objects were embedded, has guided the selection of analytical methods developed in this book. How do we make evident the order imposed on the artifacts by their makers and users? How do we achieve concordance between our methods for artifact class formation and class assignment and the underlying processes that produced the order we are attempting to recover through artifact classification? We want to determine analytical methods for uncovering types and constructing typologies that will answer these questions. To achieve this goal, our classifications must be based on methods developed in accordance with our understanding of the relationship between "material culture" and "ideational culture," a relationship created by the makers and users of those material objects through the production and use of what we refer to as artifacts.

Cultural Basis for Artifact Typologies

In his book *Systematics in Prehistory*, Robert Dunnell makes explicit the prehistorian's often implicit link between artifact and culture through his observation: "*Prehistory assumes that attributes* [of artifacts] *which are the products of human activity and which recur over a series of artifacts . . . can be treated as manifestations of ideas held in common by makers and users of those artifacts*" (Dunnell 1971: 132). This linkage provides "the means for insuring that the [classificatory] units created are useful for manipulations in terms of the concept culture" (p. 138). These two ideas—artifacts are a manifestation of the ideational domain of shared concepts and the archaeologist's access to that ideational domain is through classification of artifact materials—provide the conceptual framework for this book.

Linking the cultural domain of the artisan with the physical domain of the objects produced by the artisan is not a new theme in the study of artifact material. As noted by V. Gordon Childe, "[A]rchaeologists order their data to form a record and . . . try to interpret them as concrete embodiments of thought" (1956: 1). This has also been the basis for presuming that archaeology shares with social and cultural anthropology the goal of explicating the processes that produce the patterning we uncover when we observe the behavior of individuals and classify the objects they produced. Early twentieth century American archaeology writers such as Irving Rouse, James Ford, John Otis Brew, and Alex Krieger—who helped frame current-day American archaeological viewpoints about artifact classification—worked from the premise expressed by Dunnell regarding the relationship between the properties of artifacts and the concepts and ideas held by their makers and users (discussed in Chapter 2). What has been lacking in this endeavor is a methodology for faithfully translating empirical data into an artifact typology based on this framework while simultaneously meeting the requirement that "a typology must be ontologically grounded; that is, it must reflect some aspect of the reality it seeks to describe" (Trigger 1999: 309). The early authors only achieved partial success in delineating methods for implementing their cultural perspective. As a consequence, "[C]ulture historians . . . were extremely cautious about stating how closely their types reflected past ideas. *They were cautious because they did not know how to test a hypothesis that the reflection was accurate*" (Lyman and O'Brien 2004: 390, emphasis added).

We should not separate analytical methods for the identification of types of artifacts from the way we conceptualize how the data at hand were organized conceptually by the makers and users of the artifacts. The assumptions underlying our methods need to be in concordance with the

processes giving rise to the patterning embedded in the artifact material that our analysis is intended to discern. Our methods for discerning a type must be able to identify patterning that originated in the conceptual framework that guided the production of artifacts.

Design Constraints

The patterning cannot be reduced just to constraints on what makes an artifact effective in its intended usage as a tool. The characteristics that make for effective usage do not uniquely determine the form and shape of an artifact (Perlès 1992), but only a range of forms that would be appropriate since there are "different ways of doing the same thing" (Lemonnier 1983: 17). An additional constraint was provided by what the makers of artifacts considered to be appropriate tools. The Tasmanians of Australia—to cite a group with an extraordinarily long and isolated history—though initially having a stone tool technology similar to that of the peoples on the mainland of Australia prior to the isolation of the Tasmanian peninsula from the mainland about 8000 BP, never had or developed ground stone technology, spear throwers, boomerangs, and a variety of other tool types that were later invented on the Australian mainland despite general similarities in the resources of these two regions. Why they did not follow a trajectory similar to what occurred on the mainland has had different interpretations (see Jones 1995), but regardless of the specific reason, Tasmanian flint knappers simply continued to make artifacts within the range of what they perceived to be possible kinds of artifacts and with only relatively minor modifications over a period of several thousand years (see Read 2006 and references therein). They did not sample the full range of possible artifacts consistent with the raw materials available to them.

Lack of innovation is not unique to the Tasmanians and is also characteristic of the Australian desert culture for which the lithic sequence at the site of Puntutjarpa "presents archaeologists and anthropologists with one of the most dramatic and best-documented cases of culture conservatism in the world" and covers the period from around 10,000 BP to the present (Gould 1971: 171). In a similar vein, for the potters of Bafia of Central Cameroon, "it is not a matter of choosing from a catalogue of available procedures, but of carrying on, deliberately or not, a technological tradition" (Gosselain 1992: 572).

Cultural Constraints

Conservatism in artifact production also suggests that in addition to focusing on the functional use of an artifact as a determiner of the raw

material used and the artifact's form, the artifact classes we distinguish as types need to relate to the cultural context of artifact production and usage. This would include the particular choices made by artisans within the range of functionally substitutable forms, such as different designs applied to morphologically similar pottery objects used in the same functional manner. For the cultural aspects of artifacts, the relationship between material and kind of artifact may be less clear cut than between material and functional usage, though culture specific and consistent relationships can occur between artifact form and cultural usage. Nonetheless, when forming a typology, we are not creating order for the artifacts we have recovered; instead, we are discovering the order created by the makers and users of the artifacts, an order in which "the very process of manufacture, the techniques of chert knapping, are themselves part of [the] web of associated meanings binding people and activities" (Sinclair 1995: 51).

To a degree, this is an essentialist argument—the meaning of the individual artifact is through the definition of the category in which it has been embedded (Popper 1950: 34; Dunnell 1986)—but with the caveat that the essentialism arises from the cultural context. Unlike the biological context where an essentialist typology of species runs counter to evolutionary change (Hull 1965), as culture bearers we construct categories and through categorization we attribute meaning to what has been categorized through the properties we associate with those categorizations. As archaeologists, we can identify the essence of the constructs through our recovery of aspects of the constructed reality we refer to as culture. We want to identify those preexisting categorizations and constructs (preexisting in a temporal sense from our vantage point as researchers dealing with the material remains from past societies) to the extent possible through analytical methods. At the same time, we also need to consider individual variation among the objects within a category and the implications of that variation for our interpretation of patterns of behavior inferred from artifact properties.

Artifact Variation

The type-variety system developed for classification of pottery objects (discussed in Chapter 3) is one example of how individual variation within a type has been taken into consideration, by referring variation among individual artifacts within a type back to its purported source as variation at the level of attributes rather than modes, where modes were defined by Rouse as "community-wide standards which influence the behavior of artisans as he makes the artifacts" (1939: 17). That is, the type-variety system recognized the type at the level of

"community-wide standards," whereas a variety represented variation within that standard with respect to aspects of the artifacts that were not central to those community-wide standards.

While some aspects of internal variation have been taken into account in the type-variety system, other aspects due to factors such as resharpening or random processes (e.g., trampling) have not—as indicated by the debate over the impact of resharpening for a regional projectile point typology (e.g., Flenniken and Wilke 1989; Hoffman 1989 [1985]; Bettinger et al. 1991), or the claim that Paleolithic artifacts identified as tool types such as denticulates may (in some cases) be due simply to periglacial activity or trampling in a flint knapping context (Vallin et al. 2001). The debate over resharpening has highlighted the failure of many typologies to distinguish between variation introduced at the object level through resharpening or random processes versus variation at the conceptual level of (emic) artifact categorization. When we resharpen a knife (or repair a broken tool), we still can categorize it as a knife even though the blade may no longer have the same morphological shape it had prior to resharpening.

If we insist (implicitly or explicitly) that each distinguishable morphological form is a type from the perspective of the makers and users of the artifacts, then we ignore the fact that some aspects of form arise for reasons other than concepts being instantiated in material objects through production. Conversely, if we take a strongly materialist perspective and insist that it is only the adaptive value of individual variants that is of concern, we ignore the fact that the artifacts we analyze were categorized and produced in accordance with conceptualizations about artifacts by the producers and users for reasons more extensive than just their material and functional aspects. As culture bearers, we can easily distinguish between our cups and mugs, yet it is not easy to provide a physical definition that clearly distinguishes between them since the distinction is not simply one of form but has to with different concepts about drinking vessels that takes into account form, context of use, kind of liquid that will be drunk, and so on.

Class Definitions Based on Object-Clustering Methods: False Start 1

Attempts to recast the classification endeavor in statistical terms—couched as a way to escape from the subjectivity of so-called intuition-based classifications—did not resolve the need for analytical methods that could identify culturally salient types. The statistical methods were

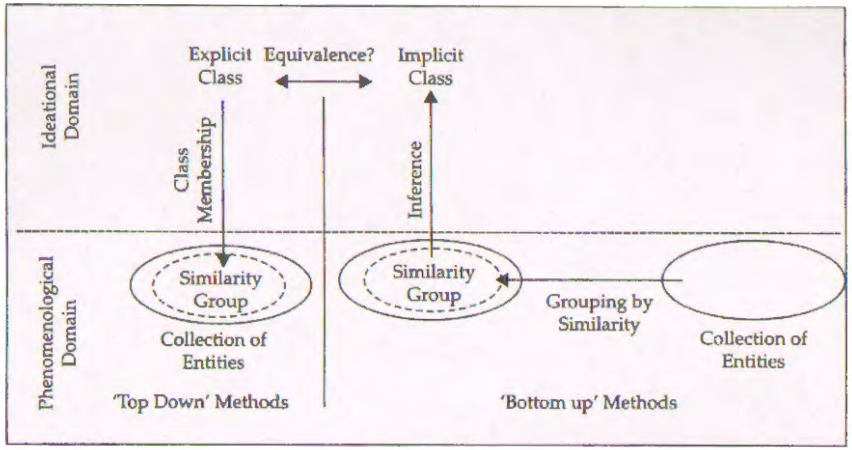
not implemented in accordance with our understanding of the basis for the patterning introduced through artisan production of artifacts (discussed in Chapter 4). Nonetheless, archaeologists have been able to produce workable typologies even in the absence of adequately delineated, objective methods (Adams and Adams 1991) by taking advantage of our enormous capacity to discern patterning via our visual senses.

When I ask students to sort pictures of projectile points from a southern California Paleo-Indian site (data analyzed in Chapter 8) into distinctive groups, they are able to achieve in a matter of minutes what escapes sophisticated clustering algorithms. The basis for the difference in performance is simple. The students are able to visually discern a dimension of the points—the concavity of the base of the projectile points—that distinguishes two different shapes for these projectile points. Visually, they can focus on that dimension while temporarily ignoring other dimensions. In contrast, clustering algorithms are not able to identify a single, salient dimension to the exclusion of other dimensions that were also measured and included in the analysis but are not relevant for distinguishing groups composed of artifacts sharing the same shape.

Numerical Taxonomy Methods

The methodology developed under the name of numerical taxonomy (Sokal and Sneath 1963)—discussed in Chapter 5—attempted to finesse the problem of assigning individual entities to underlying, implicit classes by reversing the order of analysis from first specifying class definitions as a means to form groups of entities (left side of Figure 1.1) to first forming groups of entities from which classes would be inferred (right side of Figure 1.1). Groups were to be formed by measuring the degree of similarity for all pairs of objects in the data set brought forward for analysis; that is, numerical taxonomy involved an analytical shift from using variable values to define a class to using variable values to measure the degree of similarity between pairs of objects, and to define groups of objects based on their degree of similarity from which classes would be inferred. The underlying assumption is that members of the same class are similar to each other and differentiated from members of other classes; hence, the class could be indirectly recovered by grouping objects according to their degree of similarity under the assumption that classes "have been defined because their members are similar" (Doran and Hodson 1975: 160).

Figure 1.1: "Top-down" methods: grouping entities based on an explicitly defined class. "Bottom-up" methods: grouping entities by similarity and inferring a class for which the grouped entities are class members

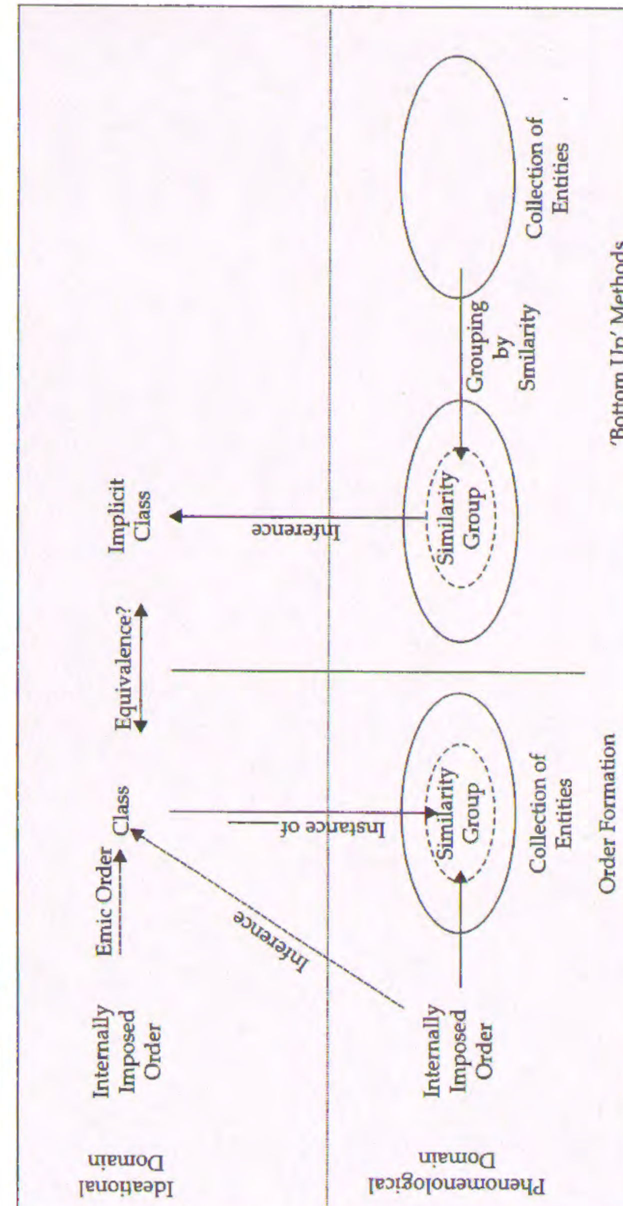


Inferred Classes

In general, there is no reason to expect an implicitly determined class inferred from grouping of objects to be comparable to an explicitly defined class unless both methods of class formation are equally responsive to the process(es) that gave rise to the patterning observed over the objects in question. In the context of biology, the primary order-producing process is evolution driven by natural selection and the working hypothesis is that diploid organisms at a point in time are objectively separable into distinct groupings we refer to as species. Whether the groupings of organisms found through similarity measures are in agreement with species that have been identified by criteria—such as boundaries for interbreeding—depends on empirical agreement between organisms grouped together as instances of a single species and organisms grouped together on the basis of a similarity measure. The species = class equation is inferred from the order imposed by evolution.

The archaeological context, though, is more complex. The process by which order is imposed on material objects through their manufacture and production takes place in a cultural milieu in which the makers and users of artifacts are embedded. The cultural framework affects the decisions made by the artisan when making artifacts using shared conceptualizations and the type = class equation may be part of the implicit emic conceptualizations relevant to the artisans (Hayden 1984; Miller 1985)—see horizontal dashed arrow, Figure 1.2—and for

Figure 1.2: Left side: group similarity through order formation processes operating at the phenomenological level (solid horizontal arrow). Order formation processes may give rise to higher-level constructs inferred from the imposed ordering (slanted dashed arrow). Cultural context introduces emic, order-producing processes at an ideational level (horizontal dashed arrow). Right side: same as right side of Figure 1.1



which the material objects are an instantiation (see downward solid arrow, left side of Figure 1.2). The left side of Figure 1.2 identifies the basic idea underlying the *chaîne opératoire* approach to the study of lithic materials (Leroi-Gourhan 1943, 1964; Lemonnier 1976, 1992; Inizan et al. 1981; Pelegrin et al. 1989)—discussed in Chapter 7—that considers not only the sequence of steps involved in the production of lithic artifacts, but also the relation between each of these steps and the conceptual systems that guided the behavior of the artisan.

The underlying assumption of numerical taxonomy analysis, though generally left implicit, is that the two methods for grouping of entities—one based on order-producing processes (left side of Figure 1.2) and the other based on similarity measures (right side of Figure 1.2)—will arrive at the same result when object similarity is the consequence of order producing processes. If this assumption were valid, then a class inferred from the group formed through similarity of entities (right side of Figures 1.1 and 1.2) would not require an explicit, existential, definition since it would be the same class arrived at through identifying the order producing process (left side of Figure 1.2).

In an archaeological context, equivalence of the two ways for arriving at a class would require that the grouping of entities based on numerical measurements and using numerical similarity methods should match the order imposed over the entities through the conceptual categories that guided artisans in their production of material objects (horizontal dashed arrow and vertical solid arrow, left side of Figure 1.2). But concordance between the numerical taxonomy methods for grouping by similarity and the order produced through conceptual categories cannot be assumed, as is discussed in Chapter 5. Briefly, the difficulty is that the former leads to hierarchies of groups and hence to hierarchies of classes, based on levels of inclusion determined by the degree of similarity required for group inclusion using a fixed set of variables, whereas the latter produces branching, taxonomic hierarchies based on using (in part) different criteria and variables for the conceptual distinctions at each branch in the taxonomy. In addition, the assumption of numerical taxonomy methods that increasing the number of measures will lead to convergence on an underlying structure for the phenomena in question is mathematically not valid in general, as demonstrated in the Appendix.

Imposed Class Definitions: False Start 2

An alternative to analytically uncovering order in the data brought forward for analysis has been to create our own order for the artifact material that we have recovered. We can form classes on the basis of imposed criteria; for example, forming a lithic blade class versus a flake class by using an imposed distinction such as blades are more than three times as long as they are wide. Or pottery material may be divided into form differences that simply represent the extreme ends of a continuum of forms. Or we may interpret shape modification due to resharpening as representing qualitative differences in form when in fact we have merely sampled part of the range of quantitative shape variation arising through resharpening (Hoffman 1989 [1985]). The latter error reminds us of Ford's (1954) argument about erroneously defining types through inadequately sampling a trait varying continuously over space. Ford considered an imaginary society with continuous, spatial variation in house forms and argued that random, sparse sampling of continuous variation would make it appear as if the sampled data varied at a qualitative, discreet level. Types defined on the basis of what appeared to be discrete differences in the sample data would lead to the erroneous conclusion that the inhabitants had discrete types of houses, when in fact house forms varied continuously.

If the goal is simply to provide a classification of the material we recover as a way to organize a large corpus of materials, then an imposed order may be appropriate. Early American archeological classifications (e.g., Rau 1876; McGuire 1899; Wilson 1899a) were of this kind, though there were exceptions such as the systematic program proposed for the analysis of lithics by Holmes (1894). But if we want to go beyond organizing the material in hand and using the classification to make valid interpretations of the patterning introduced by the makers and users of artifacts, then our classification of artifact material is constrained by needing criteria that reflect their distinctions so that we can determine—to the extent possible—the full range of the patterning and distinctions they expressed in their artifact material, whether through qualitative or quantitative dimensions.

Artifact Patterning

Determining the full range of patterning is crucial to interpreting patterning discerned through analysis. If what we identify as a type crosscuts categorizations relevant to the makers and users of the artifacts we are classifying, we thereby assign—by virtue of what it means to form a class—the same interpretation to each member of the class. Yet the members of the class are not mutually substitutable for one another when our type definition crosscuts artifact differences from the perspective of the makers and users of the artifacts. We can exemplify the problem by considering the time dimension inferred from artifact classification, a dimension that has played a major role in the interpretation of pottery types (Rice 1982).

The inferred time dimension is based on the idea that not only do individual pots and potsherds have a time dimension through being made at a particular location and point in time followed by use and eventual discard, but these objects may collectively have a time dimension that we can recover through our definition of pottery types. The underlying assumption is that the emic conceptualizations represented through our pottery types also correspond to time segments that can be seriated, or ordered, in accordance with calendrical time. The degree to which the latter can be done accurately depends first, on the time and space patterning for the introduction of a new concept that affected artifact production; second, how that concept was translated into the production of material objects through time and across space; and third, on the spatial and temporal pattern for the demise of that concept.

Space and Time Dimensions

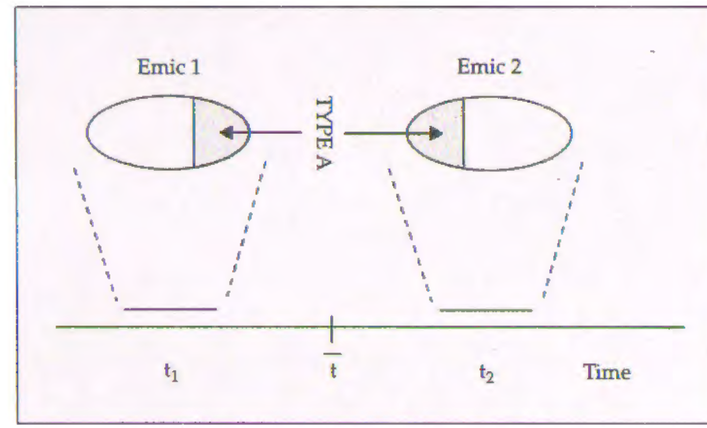
The relationship between time and space dimensions and a concept about artifact production expressed in artifacts can be recovered accurately in our artifact classification only if what we call a type is based on the instantiation of a single concept rather than being the simultaneous instantiation of several different concepts. If our type encompasses material produced according to several different concepts, with each concept having its own time and space segment in its instantiation in the form of artifacts, then there will be no single space and time segment that we can assign correctly to all members of the type class that we have distinguished.

As shown in Figure 1.3, if Type A is composed of objects that—unknowingly to us—correspond to two different conceptualizations regarding the objects (labeled Emic 1 and Emic 2 in Figure 1.3) each with its own associated time segment, then our Type A (black shaded areas in Figure 1.3) will have a mean time, $\bar{t}$, invalid for any of the objects in Type A. Consequently, the analytical methods we use for class formation cannot just satisfy general conditions for what constitutes a class as asserted by Adams and Adams (1991), but must be based on analytical methods that are sensitive to the patterning introduced by the makers of material objects.

Type Definitions Based on Qualitative and Quantitative Dimensions

Qualitative variables are less problematic for type definitions since a decorated pot has the attribute "decorated," for example, only because of decisions made by the maker of the pot, whereas a quantitative variable

Figure 1.3: Two emically relevant sets of artifacts schematically shown as ellipses and labeled Emic 1 and Emic 2. Each has a time range as indicated by the line segments along the time scale. An artifact type, Type A, has been defined that crosscuts the emically relevant groupings (gray areas of ellipses). Type A has a mean time that is invalid for all artifacts grouped together in Type A



may possibly lack direct relevance to the patterning introduced by the makers of the objects or only partially measure a relevant dimension. The analytical solution to the potential indeterminacy in the relationship of quantitative variables to type definitions lies in the expected pattern for the frequency distribution of the variable according to the process that underlies the patterning (or lack thereof) measured—even if partially—by that variable (discussed in Chapter 8).

The difference between quantitative and qualitative variables can also be expressed in terms of whether patterning in the value measured by the variable in question can be discerned on individual objects, or whether patterning is discerned "in the aggregate" through considering how a measure made on one object relates to measurements made over the other objects comprising the aggregate brought forward for analysis. Qualitative measures have joint patterning that can be discerned on individual objects and so statistical methods are not required for discerning patterning among qualitative attributes, as discussed in Chapter 8. The validity of "intuitive" typologies based on qualitative attributes is not established by translating the argument into statistical methods as discussed in Chapter 4, but by identifying attribute patterns on individual objects. In contrast, statistical methods can be relevant when the patterning that will be used in the definition of a type class is patterning in the aggregate, such as a bimodal distribution for a quantitative variable without overlap between the modes. But neither identifying

the bimodal distribution nor assigning an individual object to one of its modes can be done simply by referring to a single object in isolation, since it is the numerical value for that object—in comparison to the numerical values for other objects—that determines both the bimodal pattern and the assignment of an object to a mode.

This difference in pattern identification between a qualitative and quantitative variable has implications not only for the method of class definition, but for the structure of the data set over which measurements will be made. A qualitative pattern, such as "sherd temper, polished surface with decoration," is valid if found on a single pottery object regardless of whether the researcher's data set is representative for the domain of artifacts produced by the makers of the pottery objects. The pattern either exists on that particular object or it does not, and the pattern will not change with modification of the data set, though the frequency of its occurrence across different objects may change. In marked contrast, a pattern found in the aggregate (such as the mean length of projectile points) depends on the particular aggregate identified for analysis and the pattern may change when there is modification of the objects making up the aggregate.

In particular, the data set brought forward for analysis may initially be heterogeneous from the viewpoint of patterning introduced by the makers of the objects, and so patterning we observe in the aggregate based on quantitative variables may represent the sum effect of patterning within homogeneous subgroups and differences between these subgroups—along with the relative abundance of the subgroups in the data set. Hence, the statistical patterning we discern for the data set as a whole may have a complex relationship to the patterning of interest, the patterning introduced by the artisans. Consequently, analytical methods must include methods for dissecting a data set into homogeneous subsets according to criteria that may be initially unknown (discussed in Chapter 8). The dissection is not just a statistical issue but depends for its resolution upon our understanding of the way cultural, technological, functional, and symbolic dimensions affect the production of material objects by artisans.

Cultural Systems and Artifact Types

Artifacts are not produced in isolation but are produced in a cultural and social context of interacting individuals. Constructing a typology—a structured system of artifact types—involves more than just the application of analytical methods. It cannot be based on methods that do not reflect our understanding of how the social and cultural context of

artifact production frames and shapes the patterning arising when raw material is transformed into material objects by artisans who are part of a cultural and social system: "[B]efore we proceed to identify and delineate cultural types, we must have knowledge about archaeological cultures" (Klejn 1982: 141).

The relationship between the cultural system and the patterning we find in artifacts was well recognized by the three archaeologists (discussed in Chapter 2)—James Ford, Alex Krieger, and Irving Rouse—whom Dunnell has characterized as achieving "the synthesis of chronology and form" (1986: 167). As Rouse commented, artifacts are "the results of culturally conditioned behavior performed by the artisan" (1939: 15). But culture is not one dimensional (D'Andrade 2001; Leaf 2004) and so the relationship between culture and artifact will be multidimensional in accordance with the different cultural dimensions. Each of these cultural dimensions can be the basis for types organized in the form of typologies; the intersection of these typologies will lead to yet other ways to characterize types. This is particularly evident in the production of pottery where the dimensions of material (or paste), technique, form, and decoration all come into play yet have differing relationships to a cultural context expressed through geographical and temporal dimensions (discussed in Chapter 3).

The time and space dimension for pottery paste, for example, may overlap and crosscut the time and space dimension for pottery decoration and both may have a different time and space distribution than is found for pottery form. We may form a typology for kinds of paste, a typology for decoration (which need not be limited to pottery decoration), and a typology for form. We may then construct a typology based on the intersection of these typologies (such as pottery types defined in terms of the way paste attributes and mode of surface treatment relate to decoration), or a typology based on the intersection of the decoration and form dimensions, or even a typology based on the intersection of all three dimensions. The pottery object is thus "multidimensional in terms of meaning" (Binford 1972: 199–200; Linton 1936: 402, as referenced in Hayden 1984: 85). While this may lead to multiple classifications of the same material objects as advocated by Brew (1946) and discussed by Hill and Evans (1972), the multiple classifications are still framed by the processes underlying the structuring found in the data set brought forward for analysis.

Differences in time and space dimensions for aspects of pottery such as paste, form, surface treatment, and decoration highlight an additional source of variation that needs to be taken into account when identifying types and forming a typology. Culture can be viewed as being composed of information at various levels—ranging from factual knowledge to

conceptual systems that are the basis for social organization—and each kind of information may have its own dynamics and pattern for its origin, spread, and change. Cultural concepts and ideas may diffuse within and between populations without parallel movement of individuals as bearers of those concepts and ideas. To the extent that different aspects of artifacts are based on separate cultural information systems, the space and temporal distribution of those different aspects will not be the same, thus making the mapping of artifacts onto time and space dimensions dependent on the artifact aspect that is being considered.

Southwestern pottery, for example, has a rough ordinal sequence for temporal stability of different aspects of pottery beginning with the pottery ware as the most stable, followed by the type of pottery object expressed through a pattern of modes, and lastly the decoration applied to the surface of the pottery object (see Wheat et al. 1958: Figure 3). Distinctions in the ware dimension may be distributed in a similar manner over large, geographical regions and long periods of time. The pattern for mode combinations tends to be less widely spread and changes over shorter time intervals than occurs with the pottery paste. Finally, the decoration applied to a pottery object is the most variable of these three information systems and changes over the shortest time period. Though the expression of each of these aspects of pottery may be based on conceptual systems that are shared over communities, hence based on cultural criteria, the time and space boundaries for each of the conceptual systems need not be identical.

Measurement Systems: Heterogeneous versus Homogeneous Data

Different patterns for the space and time distribution of aspects of an artifact have direct implications for artifact measurement systems. In general, archaeological measurement systems have varied from systems designed to validate intuitively inferred groupings based on an intuitive "gestalt" (Adams and Adams 1991) to measurement systems designed to satisfy the archival property (i.e., the form being measured can be reproduced from the measurements) along with nonredundancy of measurements (i.e., the archival property is not preserved when using a smaller set of measurements [Read 1982]). Measurement systems (discussed in Chapter 6) are the foundation upon which analysis proceeds and ideally should be framed in terms of the dimensions upon which artifacts are constructed (Whallon 1982), but as Rouse (1960) discussed almost a century ago, one of the goals of analysis is to discern those dimensions.

Analytically, then, one task is to determine what Read (1989b [1985]) has referred to as "well-defined variables" (that is, variables that directly measure the dimensions relevant to the production of the artifacts in question) from an initial collection of "not well-defined variables" (that is, variables selected for measurement that may only indirectly, or even not at all, measure those dimensions). In other words, we need analytical methods that enable us to distinguish between attributes and modes in Rouse's (1939) sense of these terms—though the issue of variable identification in the sense discussed by Read is broader than just the distinction between attributes and modes. For quantitative variables, that task is addressed in Chapter 10 by considering the pattern for the frequency distribution of artifact dimensions according to whether the dimension value is a consequence of functional efficiency, a consequence of normative/cultural specification of the expected range of values for the dimension, or a consequence of random effects that do not have any particular pattern. The method for so doing is based on comparing frequency distributions across different cultural contexts and permits decomposition of an artifact as a whole into functional, cultural/stylistic, or unconstrained dimensions.

Artifact Classes and Dimensions

The analytical method for the decomposition is complicated by the relationship between dimensionality and artifact class. Well-defined variables may be class specific since the hierarchical structure of classes = types is often that of a taxonomy and not that of a paradigm.[1] The dimensions of concern upon which variable selection should be based may not be discernable without prior knowledge of the structure in the data brought forward for analysis. The data structure should be consistent with the underlying distinctions made by the artisans in the production of artifacts. In parallel with well-defined variables, we may distinguish between a well-defined data set (data having the form of a set of artifacts homogeneous with respect to an underlying process for dimensional patterning) and a not well-defined data set (data that are heterogeneous and may crosscut different processes for the patterning of artifact characteristics).

Heterogeneous versus Homogeneous Data Sets

These two sets of distinctions lead to the two-way partition shown in Table 1.1. Typically, data and variables brought forward for analysis are initially in the lower right corner cell (not well-defined variables + not well-defined data)—or what Klejn refers to as "a chaotic accumulation"

Table 1.1: Data Partition and Variable Partition

Data / Variable	Well-Defined (WDD)	Not Well-Defined (~WDD)
Well-Defined (WDV)	WDV + WDD	WDV + ~WDD
Not Well-Defined (~WDV)	~WDV + WDD	~WDV + ~WDD

(1982: 276)—since we may neither know in advance how to group data according to underlying structuring processes, nor the appropriate dimensions for analytically representing those processes. Statistical analysis aimed at constructing a typology requires that our data set should be in the upper left corner (well-defined data + well-defined variables) if the analysis is not simply to be descriptive, and instead should be identifying patterning that can be related to processes that structured the data being analyzed. Data in the upper left corner can be partitioned into homogeneous subgroups that relate to distinctions imposed by the makers and users of the artifacts. These subgroups will have emic validity, where emic refers not only to linguistically marked categorization but to distinctions marked by behavior even in the absence of linguistic labeling. The differences among homogeneous subgroups then become the basis for defining types.

Methods for moving a data set from the lower right to the upper left corner include principal component analysis as a way to reduce variable redundancy and cluster analysis as a way to form homogeneous data subsets based on nonredundant variables. But proper application of principal component analysis aimed at removing redundant variables by determining dimensions in the data set along which most of the variation among individual objects takes place assumes we begin in the "not well-defined variables + well-defined data" cell. For cluster analysis to avoid the problems we have identified with numerical taxonomy methods in the Appendix, the analysis needs to begin in the "well-defined variables + not well-defined data" cell. In Chapter 8, a recursive method introduced by Read and Russell (1996) for resolving the possible disjunction between the cell where the data set should be located before using statistical methods versus the cell in which the data are initially located will be discussed in detail as part of a method for identifying dimensions along which groups of artifacts were distinguished by their makers and users.

Forming a taxonomy for artifact classification should begin with qualitative distinctions and end with patterning expressed over quantitative variables. Topological distinctions provide the broadest qualitative distinctions, followed by geometric distinctions, then bifurcated quantitative dimensions (metric dimensions where only two values occur consistently, such as pottery either having sand temper or sherd temper but not a mix

of sand and sherd temper), and finally by qualitative distinctions based on nominalized metric dimensions—metric dimensions with a bi- or multimodal distribution.

Emic and Etic Distinctions in Artifact Typologies

The importance of including emic distinctions can be seen with a taxonomic representation of the linguistic and behavioral distinctions made by Western Desert Aborigines in Australia for their lithic material (see Figure 1.4). The taxonomy, discussed by Gould (1971), begins with *katni*, their category for chert raw material. Flake tools made from *katni* are divided into two categories, *tjimari* (knives; see Figure 1.5) and *purpunpa* (woodworking tools; see Figure 1.6). The conceptual category, *purpunpa*, includes the linguistically marked category *pitjuru-pitjuru* as well as a small/large distinction based on use of the *purpunpa* that is not linguistically marked. The smaller *purpunpa* tools were hafted and used as adzes, whereas the larger *purpunpa* tools were not hafted and used as spokeshaves, choppers, or flake scrapers. The adzes are divided into "*tula*" and non-"*tula*" based on the location of the working edge—the "*tula*" small adzes have a distal working edge and the others a lateral working edge (see Figure 1.7). The small/large distinction also relates to the kind of retouch that is applied and whether the tool is hafted.[2] Though there is neither a linguistic marking for the small/large distinction, nor for the different kinds/uses of retouch, nor for hafting only being applied to adzes and *pitjuru-pitjuru*, it is nonetheless evident that

Figure 1.4: Typology for Western Desert aboriginal lithics in the form of a taxonomy. Conceptual (linguistic terms in italics) and use-based distinctions are based on Gould 1971; Gould et al. 1971; Gould 1980: 119–120. *Tula* is not a Western Desert term

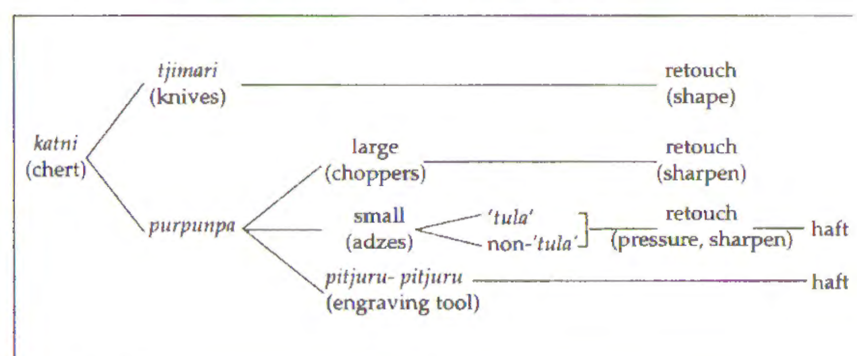


Figure 1.5: ***Tjimari*** **flake tool. Modified from Gould et al. 1971: Figure 2**

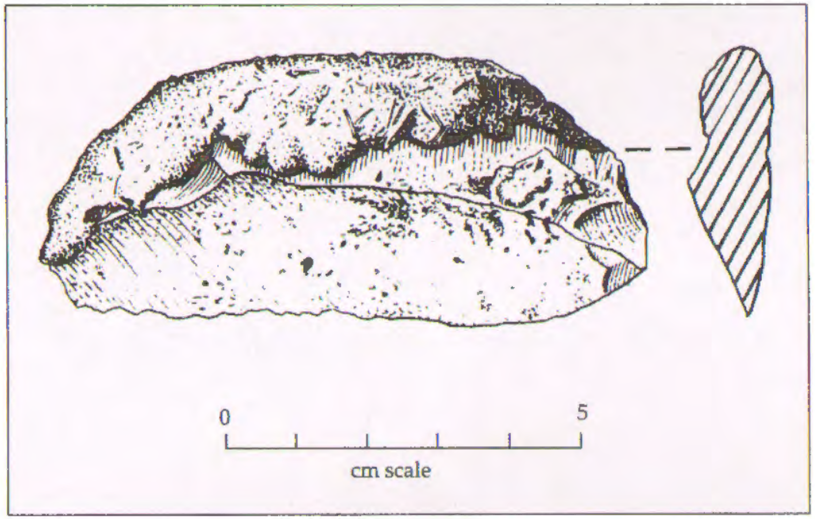


Figure 1.6: ***Purpunpa*** **flake tool. Modified from Gould et al. 1971: Figure 6**

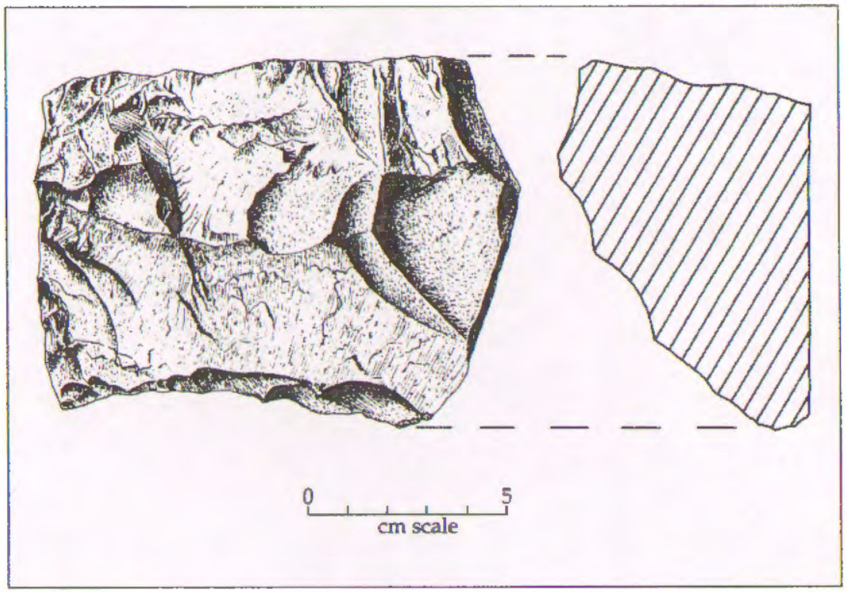
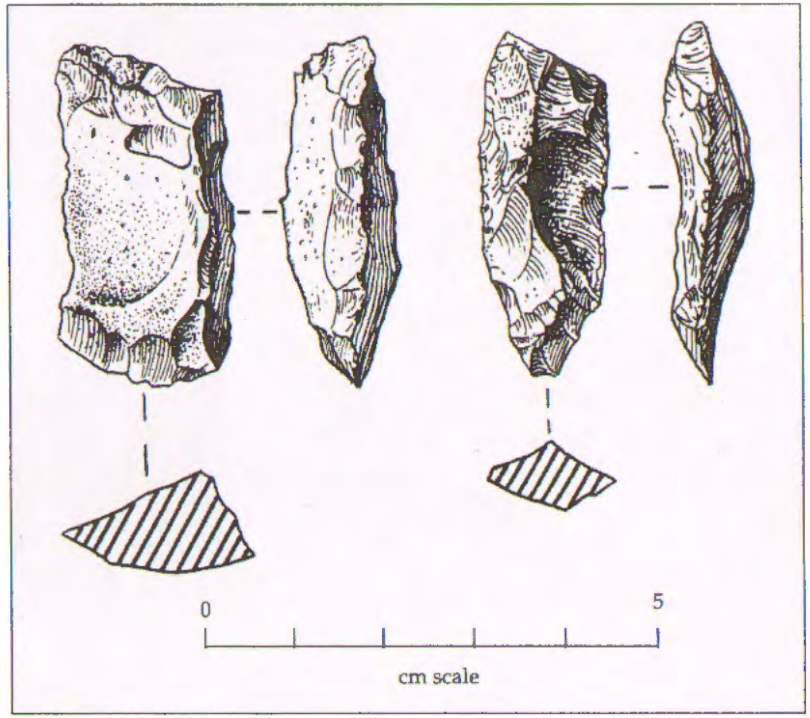


Figure 1.7: Right side: ***tula*** **slugs. Left side: non-*****tula*** **slugs. Modified from Gould et al. 1971: Figure 4**



there is a conceptual distinction based on the size of the *purpunpa* tha affects the use of a tool, the mode of retouch, and whether the tool i hafted or not.

These linguistic and behavioral distinctions refer to divisions amon the lithics that would have been made using the analytic method developed in Chapter 8 even in the absence of prior knowledge regard ing the linguistic categories of *tjimari, purpunpa,* and *pitjuru-pitjuru*. Th *tjimari/purpunpa* distinction is reflected morphologically in the lithic through a bimodal distribution in the working edge angle for these tw kinds of lithics (Gould 1971) as can be seen by comparing Figures 1. and 1.6. The tools making up the *pitjuru-pitjuru* category have a distinc ive morphology (compare Figures 4 and 5 in Gould et al. 1971), as we as only being used in a sacred context. The *'tula'*/non-*'tula'* distinctio is well recognized by Australian archaeologists (Gould 1971) an

was first identified by Horne and Aiston (1924). The behavioral distinction in the use of adzes versus choppers according to size suggests that this group of lithics is not homogeneous in terms of size variation. Correspondingly, *purpunpa* other than the *pitjuru-pitjuru* would be analytically divided by a small/large distinction based on the shape of a frequency distribution for the size of the *purpunpa*. (Though Gould does not provide data on the pattern for the frequency distribution of the size dimension for the *purpunpa*, the size difference between the two groups of *purpunpa* can be seen by comparing Figures 1.6 and 1.7.) Retouch was applied differently according to the kind of tool, as indicated in Figure 1.4, and thus retouch leaves a different "signature" for each of the relevant groups of lithics that can be analytically distinguished. Finally, the haft dimension only applies to the small *purpunpa* and the *pitjuru-pitjuru*. Though there may not be any direct evidence for hafting, the size of the small adzes seems to require that they be hafted (Gould 1971).

Gould's ethnographic example illustrates well the general goal for analytic classification of artifacts: formulate a structure for artifact classes wherein each division in the structure is based on an empirical characteristic (or characteristics) that relates to conceptual/ behavioral distinctions made by the makers and users of the artifacts, and where each class in the structure is homogeneous in the sense that no criteria for further subdivision of the class has emerged from analysis of the data set brought forward for study. The structural form that arises for linking the artifact classes is likely to be that of a taxonomy.

There are two additional aspects for a taxonomy of this kind that have not yet been addressed and are the basis for the methods presented in Chapters 9 and 10. One relates to the structure derived from considering the frequency of usage of the artifacts for each of the taxonomic categories; the other relates to the evolutionary development of, and change in, a taxonomic structure.

Frequency Counts and Artifact Typologies

The frequency counts for artifacts in the taxonomic categories and leads to methods for the analysis of contingency tables discussed by Dwight Read (1974b). Read considered the structure implied by frequency counts in a multidimensional contingency table based on a model of variable interaction for the taxonomic data being analyzed in the form of a contingency table. What frequency counts measure with respect to artifact typologies was misleadingly and incorrectly tied to the formation of artifact types by the invalid link (discussed in Chapter 4) that

Albert Spaulding (1953, 1960) made between types defined as patterns of association of attribute values and the pattern of association of variables determined through statistical methods. The latter led to his idea that types are determined by nonrandom association of attributes as measured by statistical methods and so it appeared Spaulding had shown how "artifact types could be objectively defined and replicated" (Aldenderfer 1998: 98).

The reference to statistical methods requires that attributes be the variables and not the values of the variables for a specific artifact. Though the linkage between type definitions and association of attribute variables advocated by Spaulding was questioned (Dunnell 1971; Whallon 1972), it nonetheless became the basis for attempts to develop objective methods for formation of artifact types and led to the subsequent failure to accommodate the practical reality (and validity) of intuitive typology construction based on patterning of attribute values as discussed by Adams and Adams (1991) with the rigor of statistically based quantitative methods.

Patterning in frequency counts reflects the usage, not the definition, of artifact types. The attribute combinations are—directly—the basis for the definition of types when the attributes are modal values. The frequency counts are a consequence of the use of those artifact types. Different types based on the attribute combinations present in a contingency table may have had similar frequency of use—as measured through frequency counts—due to commonality in the use of the artifact types, but the similarity in the frequency of use does not convert the different attribute combinations into a single type. The analytical methods discussed by Read (1974b) provide a means for determining the pattern for type usage expressed in the form of frequency counts in a multidimensional contingency table, hence to patterning among artifact types due to frequency of usage. We will call a group of artifact types with similar patterns of usage, a *usage type*.

Function, Style, and Evolutionary Change in Artifacts

In Chapter 10, we consider ways to reconcile the static nature of a typology (Neustupný 1993) with the underlying pattern of evolutionary change in the historical formation of artifact types as part of an evolving cultural system. That such reconciliation is needed (Gallus 1977) is indisputable since the cultural context for the pattern of artifact production arose through an evolutionary process. Less clear, though, is the particular mode of evolutionary change that is relevant to the origin of—and structure for—artifact types determined through combinations of modes. Darwinian evolution based on transmittal of traits to individuals and

change in frequency of traits through individual fitness has been invoked as an explanatory process for the evolution of artifact material (e.g., Barton and Clark 1997; O'Brien and Lyman 2000; Hart and Terrell 2002; Shennan 2002). This has led to incorporation of more recent evolutionary arguments (e.g., Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985) that focus on the determinants of direct phenotypic transmittal of traits from one individual to another through a transmission process such as imitation of behavior. While the latter can accommodate the dissemination of behavioral traits on time scales that are too rapid for change in frequencies driven by individual or inclusive fitness, it still may not be able to accommodate the way in which cultural information systems arise and spread as shared conceptual systems—thereby forming the cultural context within which artifact production and usage takes place. Evolutionary arguments need to be grounded in the processes through which cultural evolution takes place, just as the methods for the formation of artifact typologies need to be grounded in the cultural processes through which patterning in the artifacts has been introduced by the makers and users of the artifacts.

This brings us back to where we started. Our artifact classifications should provide insight, as Krieger put it, into the "meaning of the myriad works of man" (1944: 275). To do this, our methods for discerning patterning in the artifact material that we recover through excavation must be in agreement with the culturally framed synchronic and diachronic processes involved in artifact production. This implies that our analytical methods need to be framed by concordance among what we measure on artifacts, what were culturally salient dimensions for the production of artifacts, and our methods for organizing (in the form of typologies) the patterning that we analytically uncover. The early American writers on artifact classification—the topic of the next chapter—laid out the conceptual groundwork for this culturally based approach to artifact classification.

2

Historical Background

The theme of this book, the method and theory of artifact classification grounded in the culturally framed conceptual system of the artisans and users of artifacts, is not new. Some of the earliest archaeological writers on classification in archaeology took a cultural perspective as the starting point from which classification should proceed. One of these writers was Irving Rouse, an archaeologist who laid out much of the conceptual framework upon which this book is based.

Rouse: Classification and Culture

In his monograph *Prehistory in Haiti: A Study in Method*, Irving Rouse (1939) proposed a conceptual foundation for artifact classification based on the notion that a classification should be grounded in the cultural context for the makers and users of the artifacts. Rouse began by presenting evidence supporting six propositions for the relationship between concepts held by artisans and the material form of the artifacts they produced. The first proposition—later expanded upon by Robert Dunnell (1971) in his book *Systematics in Prehistory*—signals Rouse's shift from viewing a classification as a way to label artifact groupings to viewing a classification as representing concepts held by an artisan as a member of a community. His first proposition states, "1. Culture does not consist of artifacts. The latter are merely the results of culturally conditioned behavior performed by the artisan" (p. 15).

Rouse had originally classified the Fort Liberté artifacts according to the scheme set forth by McKern in which one assumed that the artifacts, rather than the concepts of the artisans and their consequent behavior, represented the cultural information to be used for culture history reconstruction (p. 9; p. 11). Rouse was now concerned with "the relationship between the artifacts and the aborigines who made and

used them" (p. 16) in keeping with his desire to develop a theory of classification grounded in the understanding that ethnographers have of culture. Rouse argued that if one takes seriously Tylor's definition of culture as consisting of the "habits and capabilities acquired by man as a member of society" (Tylor 1929 [1871]: 245, as quoted in Rouse 1939: 16), then it is not the physical object but the concepts underlying the production of the physical object that are part of culture.

Rouse was not so much rejecting the commonly held notion of artifacts being part of "material culture" as asserting that the latter is too limited a notion of how artifacts relate to culture. They are not simply another kind of culture—material culture—but are inextricably linked to a conceptual system held by the artisans and users of artifacts, and the goal should be to elucidate that conceptual system.

Reconstructing Culture History

In keeping with the archaeological issues of the time, Rouse was primarily addressing methods for reconstructing culture history through analyzing the Fort Liberté artifacts that provided the database for his monograph. But in order to develop a space/time framework, Rouse argued that it was the conceptual framework within which the artifacts were produced that provides the information needed for reconstructing the culture history of a bygone society (1939: 11). Artifacts, in his view, have a continuing history and changing set of meanings by the fact of their physical existence through time; hence, the physical artifact per se is not "culture." He argued, "[C]ulture cannot be inherent in the artifacts. It must be something in the relationship between the artifacts and the aborigines who made and used them. It is a pattern of significance which the artifacts, have, not the artifacts themselves" (p. 21). What the archeologist wants to know, he suggested, is not the fact of an artifact being produced at a particular historical moment and location in space, but how the conceptual framework underlying that production is distributed in time and through space among culture bearers.

Because Rouse drew much of his inspiration for theorizing about artifact classification from contemporary ethnographers (such as Edward Sapir) and their arguments about the nature of culture, his viewpoint presages the notion of "archaeology as anthropology" (see Rouse 1939: 15). In Rouse's framework, behavior and its conceptual basis should be the focus of artifact classification, and the behavior that primarily interested Rouse was the behavior engaged in by the artisan that leads to the production of the artifact.

This posed a quandary since Rouse separated classification from the characteristics of the artifacts and wanted to focus on the conceptual

basis for the behavior engaged in by the artisan, not all of which need relate directly to characteristics of the artifacts. Conversely, there may be features of the artifact that can be distinguished by the researcher that did not have significance from the viewpoint of the artisan.[1] Rouse attempted to avoid the quandary by distinguishing between features or aspects of the artifact that have, for whatever reason, been selected for consideration by the researcher versus those features that had salience for the makers and users of the artifacts. The former he referred to as *attributes* and the latter as *modes*. Thus, modes are those features of an artifact in which the behavioral and conceptual relationship between artisan and artifact is expressed.

Modes, Attributes, and Types

Rouse's solution is only partial, though: in his view, a type had to do with the pattern formed by several modes, but not all modes need be involved in defining types. If a type refers, say, only to the particular shape observed over a series of artifacts such as "triangular shaped projectile point with a concave base," neither the technology nor type of material used to manufacture the artifact enters into the definition of that type even if the technology or type of material has cultural salience for the makers and users of the artifacts. Consequently, even if the modes have been distinguished, still unspecified are the modes relevant to an artifact pattern distinguished as a type.

Rouse was not consistent in his distinction between a mode and an attribute. On the one hand, he considered modes to be attributes with cultural salience, in contrast to attributes of interest to the archaeologist but not having cultural salience. Among the latter he included traits that only reflect biological, chemical, or physical properties of objects or are due only to the "personal idiosyncrasies of the artisans" (Rouse 1960: 313). Modes viewed as traits observable on individual artifacts are thus distinguished from other traits identified by the archaeologist through the claim that the trait = mode is part of the instantiation of a conceptual system that has guided the artisan in his or her production of the artifact. We will call this definition of a mode, *mode*$_1$.

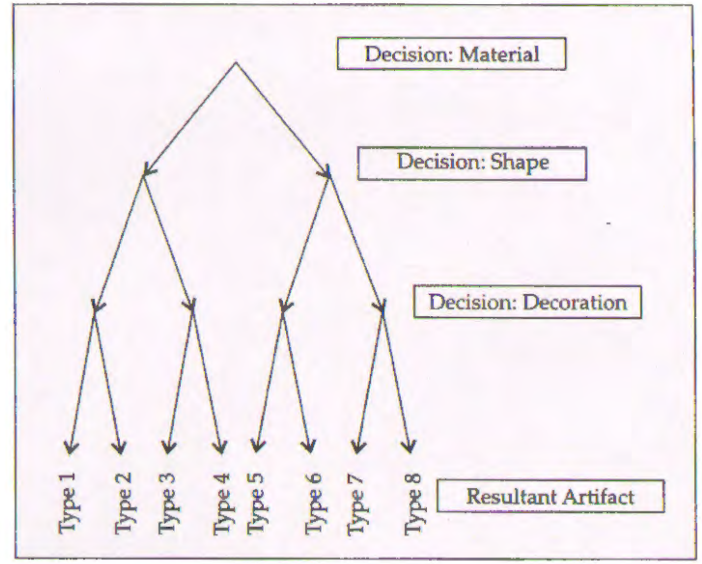
On the other hand, he later defined a mode to be "any *standard, concept, or custom which governs the behavior* of the artisans of a community, which they hand down from generation to generation, and which may spread from community to community over considerable distances" (Rouse 1960: 313, emphasis added). Here a mode does not refer to an aspect of an artifact, but to a conceptual framework that guides the artisan when producing an artifact. In this usage, a mode is part of the ideational domain

of the artisan shared among other culture bearers. We will refer to this definition of a mode as *mode*$_2$. His two dimensions of transmittal—vertically across generation and horizontally between communities—are a forerunner of what has now become known as dual inheritance (Cavalli-Sforza and Feldman 1981; Boyd and Richerson 1985), in which a distinction is made between phenotype transmittal arising through genetic transmission versus phenotype transmittal arising through processes such as learning and imitation that can occur either among individuals of the same generation (horizontal) or across generations (vertical).

In order to relate his notion of mode and type to artifact production, Rouse distinguished the presumed conceptual sequence underlying the procedures for artifact production. The conceptual sequence minimally leads from choice of material to choice of shape and decoration, and then to a particular type of artifact made by an artisan. In this context, a mode$_2$ links the procedure by which an artifact type is produced from the perspective of the artisan (see Figure 2.1) to the features of artifacts. That is, mode$_2$ represents a shift from a mode being a distinction among artifact traits (mode$_1$) to identifying the conceptual decision points the artisan presumably undergoes in the process of manufacturing an artifact, such as the criteria used for choice of material, choice of technique, shape, decoration, and so on. This shift led to his claim that the artisan's procedure of going from concept to artifact type can be represented by a sequence of division on the basis of modes (=mode$_2$ [Rouse 1960: 116]). Here Rouse was attempting to formally represent, with his notion of mode and type, the conceptual process that underlies the artisan's production of an artifact illustrated in Figure 2.1 for the dimensions of material, shape, and decoration.

Rouse's shift in the meaning of a mode is problematic for his notion of a type. Rouse had distinguished between a group of artifacts and a type, with the latter representing "an abstract kind of artifact which symbolizes the group" (Rouse 1939: 11); that is, the type is the class definition as opposed to the group of artifacts that are members of the class (Dunnell 1971). A type is characterized by a "pattern of artifact characteristics" (Rouse 1939: 11); in this context, the modes (= mode$_1$) are the attributes making up the pattern upon which the class definition is based, not the concepts (= mode$_2$) underlying the artisan's procedure for the production of an artifact. Thus, under this definition of a type, one might use the mode (= mode$_1$), incised lines, as part of a type definition applicable to certain kinds of pottery. Yet later a type becomes, for Rouse, "a complex of modes which is diagnostic of a certain class of artifacts and which serves to differentiate that class from all other classes" (1960: 315–316).

Figure 2.1: Rouse's decision sequence leading to the manufacture of an artifact



From the perspective of viewing the mode (= mode$_2$) as representing the concept and not its instantiation in the form of incised lines, one must use "the technique of incision as a criterion for taxonomic classification" and not "the attribute of incised lines" (1960: 315).

A mode became, in Rouse's usage, both a concept (= mode$_2$) and the instantiation of that concept (= mode$_1$). Rouse ended up with a long, unrealistic list of eighty modes for the artifacts upon which his study of the prehistory of Haiti was based (Rouse 1939, 1941, 1952). But artisans clearly do not go through an eighty-step decision process when going from raw material to finished artifact. The modes distinguished by Rouse for the Fort Liberté artifacts—such as Lug, Cylindrical Lug, Wedge-Shaped Lug, and Flat Lug on the one hand, versus modes such as Ornamentation Before Clay Was Relatively Dry and Affixation (the process of adding a lump of clay for decoration) on the other—make it evident that procedure and outcome were treated equally as modes.

Nonetheless, his goal of basing classifications on distinctions that have salience for the artisans and users of artifacts is clear even if the execution is sometimes flawed. Rouse's distinctions among attribute, mode, and type then led him to outline a scheme for the analysis of artifacts in which he distinguished between *analytic* (Whiteford 1947) and *taxonomic* (Phillips 1958) classifications, depending on whether the goal is to determine modes or types. Analytic classification refers to the process by

which the researcher determines what constitutes modes (= $mode_1$) as opposed to attributes. Taxonomic classification refers to identification of patterning displayed among artifacts through the way two or more modes might be brought together on the same artifact. The importance of the distinction lies in the fact that Rouse did not consider modes merely as a means to distinguish types; rather, modes—especially in his second usage of the term—became the means to model the conceptual and cultural framework within which artisans operated.

Instantiation of Modes

Since a type definition can be based only on some of the modes relevant to artifact production, classifications based on modes can lead to alternative arrangements of the same artifact material. Thus, if one begins with the mode, material used, artifacts could be grouped according to type of material—thereby leading to the standard practice of field archaeology to sort artifacts by type of material such as clay, stone, bone, wood, reeds, etc. However, rather than being a pragmatic sorting, the presumption in Rouse's framework is that one should be sorting by kind of material only to the extent that the latter is relevant to discriminations made by the artisans and by criteria that were part of the conceptualizations of the artisans. Sorting into clay/pottery versus stone/lithic, for example, is not done simply for pragmatic reasons but only if it represents a fundamental conceptual distinction made by the artisans and users regarding the meaning, use, and purpose of pottery versus flint artifacts. On the other hand, sorting pottery according to source of clay using neutron activation techniques may be useful as an index of raw material source, and the latter may have implications regarding the scope and geographical extent of the resource base used by the occupants of an archaeological site, but the latter might not have any culturally grounded implication for artifact production and artifact usage.

The same artifacts could also be sorted according to usage (such as storage versus serving vessels) and that sorting might crosscut a sorting based on material. Similarly, sorting on the basis of shape might crosscut a sorting based on usage, and so on. In effect, Rouse implicitly recognized a distinction between a concept (= $mode_2$) and its instantiation in the form of a feature of a physical object (= $mode_1$). His confounding of two usages of concept of a mode, though, did not allow him to make it clear that a distinction between a concept such as "storage vessel" and its instantiation as a physical object involved yet another concept—the relationship between a group of similar artifacts and an abstract representation for that group. The concept of "storage vessel" has instantiation

at the conceptual level in terms of perceptions about what shape, form, material, technology, and the like are part of the design for a storage vessel. The actual storage vessel made by the artisan and recovered by the archaeologist brings to bear both the instantiation of the concept of a storage vessel in the form of a particular design and the physical instantiation of that design as a concrete object in the form of an artifact.

While the example of a storage vessel has direct implications for what might constitute a design of an object due to the intended functionality of the artifact that is produced, other concepts do not entail the same degree of constraint for the instantiation of the concept as a design. For example, the concept of "protection against potentially harmful spirits" can be instantiated for some societies in the form of an object called a talisman, but the design of a talisman is not constrained a priori by the underlying concept and instead has a design that—for whatever reason—is believed to be efficacious in guarding against harmful spirits.

Problems With Identifying Modes

The weakness in Rouse's implementation of his scheme lay in its first step: isolation of modes. In effect, Rouse had no methodology for the "discovery" of modes other than the archaeologist's intuition as to what constituted a "community-wide technique design, or other specification to which the artisans conformed" (1939: 18), though he did identify three steps for finding modes: (1) determine the individual attributes for each artifact; (2) select "the attributes which seemed to be most significant for a culture historical study" (1939: 26); and (3) provide a name for each of the attributes isolated in Step 2. While Step 2 is specified in terms of a cultural historical study, it is evident that Rouse's intent was to isolate the attributes that had cultural salience since it was the latter that provided the information needed for a cultural historical study. But Rouse had no independent criterion for how one might distinguish a culturally salient attribute from a non-culturally salient attribute, and so the methodology could easily become circular.[2] In practice, Rouse seemed to rely on attributes that clearly were deliberate, such as a particular design element on pottery or whether a lithic is retouched along its edge (1939: 46–54).

With regard to types, Rouse's procedure was even less closely tied to the analytical framework he set forth and his pottery types are little more than a claim about similarity in the way pottery artifacts were manufactured. For the Fort Liberté artifacts, for example, the entire edifice he constructed about types as patterns of modes/attributes is reduced to recognizing two types: Meillac Type Pottery and Carrier Type Pottery, each named for the site from which the pottery material was recovered.

In contrast, lithic types seem to represent functionally different kinds of objects: he distinguished among Flint Dagger, Flint Knife, and Flint Scraper. In neither case are types determined from considering the modes and the possible combinations of modes that could be realized on an artifact.

The disparity between conceptual argument and lack of a method for implementation of the conceptual argument is made more striking by Rouse's outline of a procedure for forming types that presages later attempts to objectify archaeological classification. Rouse suggested that types should be formed by subdividing the collection of artifacts, first by one mode (= $mode_1$), then by another mode, and so on until homogeneous groups of artifacts are obtained—hence making the combination of modes that determine a homogeneous group the class definition for that homogeneous group of artifacts. What Rouse lacked was a methodological basis for carrying out the subdivision procedure except for relatively simple cases. Unless the data are structured in the form of a paradigm, the order in which modes are used to make subdivisions has significant consequences for the formation of homogeneous groups of artifacts. A variant of this method of identifying types was later implemented by Robert Whallon (1972) when Whallon attempted to provide an objective basis for Ritchie's Osweco pottery types. Yet another variant, numerical taxonomy, was implemented for types based on quantitative measures.

In effect, Rouse had identified the reasoning underlying numerical taxonomy—with the exception that he provided a criterion for choice of variables that should enter into the analysis when he asserted that groupings should be based on modes. In addition, he suggested that the groupings could be done by sorting artifacts "according to the most frequent combination of modes (Shepard 1956: 322–332)" (1960: 316), which clearly presages the methodology later introduced by Albert Spaulding. But Rouse did not appreciate that these two procedures are not identical and even considered them as equivalent to the very different procedure of intuitive sorting into homogeneous groupings advocated by Krieger (1944). What neither Rouse, nor later Dunnell (1971) in his book *Systematics in Prehistory*—which is based on Rouse's arguments—nor Adams and Adams (1991) in their book *Archaeological Typology and Practical Reality*—which advocates a return to intuitive methods—realized is that an objective method for distinguishing culturally salient attributes (discussed in Chapter 8) could be derived by using simple statistical concepts based on what is implied by the notion that a mode is an attribute having community-wide agreement on the form of its expression.

Rouse's view that classification should be based on concepts derived from the ethnographic study of cultures was paralleled by an alternative view that classification should be done in analogy with biological classification (e.g, Gorodtsov 1927; Gladwin and Gladwin 1934; McKern 1939). This viewpoint was challenged effectively by Brew (1946) and the biological classification framework would not be relevant here except for its recent reincarnation under the guise of evolutionary archaeology. The biological focus has now shifted from the form of classification to a theory of artifact change based on Darwinian evolution, but the general thrust is the same. In both instances, it is assumed that the relationship between artifacts and change in the form of artifacts is essentially the same as for biological entities and change in the form of biological entities since both are a consequence, it is claimed, of natural selection and drift (O'Brien 2005).

We will discuss evolutionary archaeology and its relationship to classification in a subsequent chapter. Here we will consider some of the arguments against a biological analogy raised by John Otis Brew and why this led him to view archaeological classification as essentially an arbitrary task guided primarily, if not exclusively, by the goals of the archaeologist. Adams and Adams (1991) have also revived the conclusion reached by Brew about what constitutes archaeological classification—given that it is not the equivalent of biological classification transformed to an archaeological context—in what they call a pragmatic approach to classification.

Brew: Archaeological Classification versus Biological Classification

In his important article "The Use and Abuse of Taxonomy," Brew (1946) considered in detail the claims regarding the similarity between archaeological classification and biological classification and found them wanting. In part, Brew was also criticizing what he saw as a largely uninformed approach by archeologists to systematics in which it was assumed that there is a single "correct' taxonomic system" (p. 46). Instead, he argued, classificatory systems "are merely tools, tools of analysis, manufactured and employed by students, just as shovels, trowels, and whisk brooms are tools of excavation" (p. 46); from this, he concluded that "'types' are not 'found'" and that "[t]here is no such thing as *the type* to which an object 'belongs'" (p. 46). This led to his claim that "we advocate not less but more classifications of a given series of objects" (p. 46).

His other main theme had to do with the way in which "[o]ur systematics has been borrowed and adapted from biology" (1946: 46), though the biological analogy had already been rejected in southeastern U.S. ceramic research (Ford and Griffin 1999 [1938]). The borrowing posed serious problems since it implied that cultural material should be considered as if they are equivalent to biological phenomena. The latter,

Brew argued, distorts both because it implies relationships that do not exist in artifact material and because it "inevitably distorts true cultural relationships" (Steward 1941: 366, as quoted in Brew 1946: 47). In addition, Brew argued, even within biology, taxonomic systems do not fully express the properties that arise through genetic systems; hence, one can hardly expect such systems to show "relationships between objects which do not receive their characteristics through the transfer of genes, in other words, where actually such relationships do not exist" (1946: 46). In particular, the assumption that types in some sense are to be discovered rather than constructed by the archaeologist depends upon a false analogy with biology, he claimed, where presumably "natural" groupings known as species exist. Brew correctly pointed out that the concept of a species is hardly without controversy in biology, and if it is problematic in biology, its supposed equivalent—the type—is even more problematic in archaeology.

Finally, and central to Brew's argument, is the assumption that artifact material are "part of a continuous stream of cultural events" (1946: 48). He quotes Kidder's comment that "[t]he division of the Glaze ware of Pecos into six chronologically sequent types" is one that Kidder initially considered to be "types as if they were definite and describable entities" even though in fact they are "merely useful cross-sections of a constantly changing cultural trait" (Kidder and Shepard 1936, as quoted in Brew 1946: 49). Kidder's comment and Brew's similar view about the continuity of the features of artifacts through time and across space presages the later paper by Ford (1954) with his imaginary "Gamma-gamma" culture, written in challenge to Albert Spaulding's claim to be able to objectively discover and not just arbitrarily construct types.

Brew went on to argue that if the archaeologist does not "discover" artifact types, then classification becomes a method of analysis and the validity of any particular classification scheme lies in whether the method that has been identified allows the archaeologist to achieve one's stated goals. This viewpoint is echoed more recently by Adams and Adams in their assertion that for typologies, "effectiveness for their intended purpose, not divine will or natural order, is their ultimate legitimation" (Adams and Adams 1991: 88); therefore, when we recognize that "typologies are made by us, for our own purposes, we may hopefully be liberated from the deception of mythology and the often time-wasting search for 'reality'" (1991: 88).

Problems with "Natural" Classifications

Brew usefully commented that the notion of a supposedly natural classification based on using all possibly distinguishable attributes—as advocated by biologists such as Gilmour (1940)—was fundamentally misguided since such a classification would likely end up with each object in its own unique class; there is always some aspect of one artifact that differentiates it from another artifact. Brew recognized that the problem, in part, lay with what is meant by "all attributes." The solution to reducing classification to each item being in its own class lay in the selection of supposedly significant attributes or variables, but how such variables were to be selected, he argued, is far from obvious. The same problem arose later with the development of numerical taxonomy methods (Sokal and Sneath 1963), wherein the problem of using all possible variables in a classification was supposedly resolved by allowing for polythetic and not just monothetic definitions of types; hence, one did not need to select which variables would be used when constructing a taxonomy. This supposed solution (discussed in detail in Chapter 5) assumed that formation of types could essentially be reduced to grouping objects (biological objects in the case of biological taxonomies and material objects in the case of archaeological taxonomies) according to a pairwise similarity measure based on all measures made over the artifacts, along with an algorithm for grouping or clustering together entities according to that similarity measure.

Another part of the problem with the "natural" taxonomy idea lay in the presumption that there could be a single taxonomic scheme for all artifact material regardless of time or space, and so we would supposedly have, "all of the pottery of the world, or the cultures of the world, arranged according to a single descriptive classification according to criteria *arbitrarily agreed upon*" (Brew 1946: 51). Brew correctly noted that investigation of relationships other than those displayed in that classification scheme would require using other criteria, and hence would lead to a different classification, thereby contradicting the assumption of a single, universal classification.

Though Brew identified a conceptual problem with the notion of a single, all-encompassing classification system, what he did not observe is that the problem with the "natural" classification that presumably could encompass all artifact material of a given kind falters on precisely what concerned Rouse. The choice of attributes is not simply the archaeologist's choice if the goal is to elucidate the conceptual framework underlying the production of the artifacts being investigated by the archaeologist. Rather, the choice must satisfy the criterion of cultural saliency. Hence, the claim of a single, all-encompassing classification system is equivalent to claiming that all artifacts were, and are, produced according to a single, universally shared conceptual/cultural system. If we speak of cultural *systems* and not *the* cultural system, it follows that the attributes and

material dimensions that are the basis for patterning mapped onto material objects by artisans are culture specific, and hence classifications of artifacts must at least be culture specific.

Process and Structure

In the case of biological entities, one presumes a single process—natural selection—as the basis for systematic structure and organization and the criterion of homology for choosing among possible attributes or variables to be used in forming a classification. Biological classifications are based on homologous traits under the presumption that two synchronous species sharing a homologous trait must have had a single, ancestral species from which both are derived via natural selection. The form of biological classification in the form of a taxonomy arises as a consequence of this theoretical framework, which identifies the primary structuring process for the order and organization one sees in the phenomena of interest to the biologist. The analogous argument in an archaeological context resides with identifying the process(es) by which order and organization arise within the domain of culture and is expressed in the form of artifacts, not by simply trying to build a taxonomic scheme that mimics the taxonomic system of Linnaean classification. Brew listed Gladwin and Gladwin (1930, 1934), Hargrave (1932), Colton and Hargrave (1937), and Hawley (1938) as examples of the latter error.

Brew mainly critiqued the problems that arise when one tries to construct archaeological classifications with form analogous to that of biological classifications. He only briefly considered what might be the structuring processes for artifact material with his comment that "we deal with a succession of human deeds and relationships. In archaeology we study the material manifestations of these deeds and relationships and attempt to reconstruct the latter" (p. 59). In the end, he only offered generalities such as needing more rather than fewer classifications, or that classifications depend on the goals of the researcher. While these generalities are valid in a broad sense, what he and subsequent writers who make similar arguments fail to realize is that if they are to achieve the general goal that Brew identified of understanding social systems through artifact materials, then the structuring processes underlying the order and organization that can be observed in artifact material need to be expressed in a classification according to what we understand about the nature of cultural systems and the linkages between cultural systems and artifact material. This problem resurfaces in the recent attempt to construct a theory of change in artifacts by simply recasting the theory of evolution driven by natural selection acting on fitness differences in archaeological—rather than biological—terms, without addressing the more fundamental question of whether variation and change in a cultural context occurs by processes that are isomorphic to biological processes.

Yet in a general sense, Brew's underlying message to his fellow archaeologists is as valid today as when he wrote his critique of classificatory practices and schemes. Beyond the specific criticisms he raised is an overriding concern with the need for archaeological systematics to be just that: systematic, but not as a goal in-and-of-itself. Instead, the broader goal must be to "relate our newly gathered information scientifically to the immediate problems of human life and society, through an analysis of the problems and achievements of other peoples, toward a better relationship with our physical and social environments" (p. 65), a goal that has recently been restated by a group of archaeologists who want to address the issues and problems that confront present-day societies through our understanding of past societies (van der Leeuw and Redman 2002).

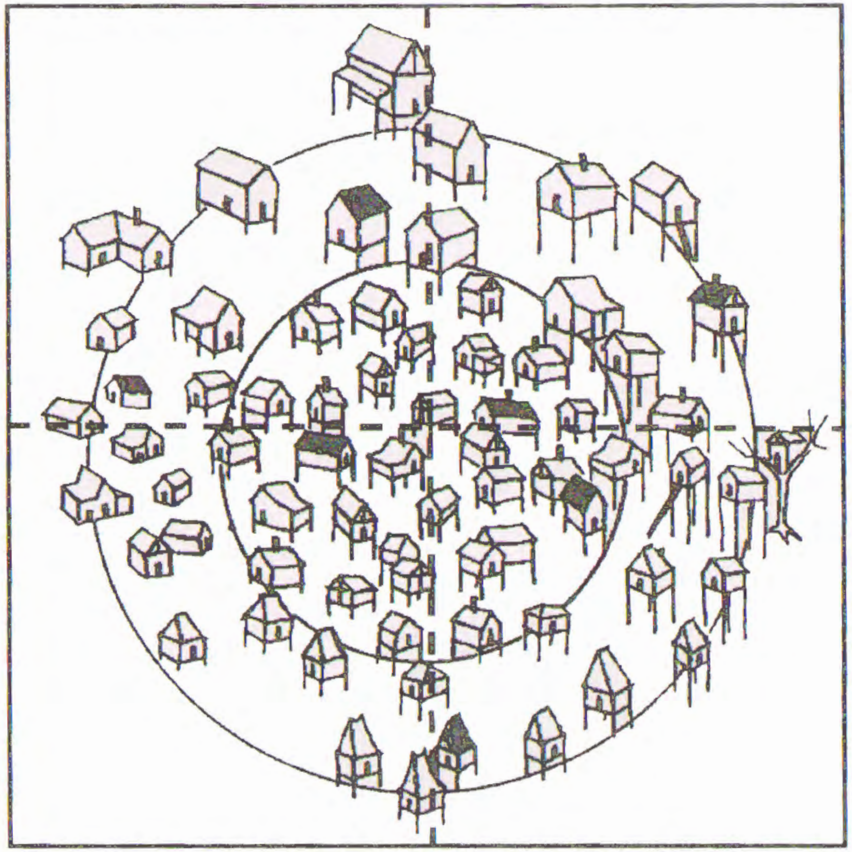
Underlying Brew's criticism of classification as practiced by the archaeologists of his time is the presumption that "we are dealing with a cultural continuum which is *continually changing*" (p. 65). Hence, he argued, it is both problematic to formulate typologies that assume discreteness when there is continuity and to formulate typologies that treat artifacts as if they are static entities.

The implications of the assumption of a cultural continuum was taken up by J. A. Ford (1954) in what came to be known as the Ford-Spaulding debate. Though Spaulding is generally viewed as the "winner" of that debate, the two protagonists were largely talking past each other. Spaulding was concerned with statistical methods for discovering patterns of co-variation in artifact material; Ford was concerned with how the spatial and temporal distribution of artifact material could create the illusion of discrete types of artifacts, when in reality one simply had variation continuous over space and through time. Ford formulated his argument by hypothesizing an imaginary culture, the Gamma-gamma people from the Island of Gamma, and the variation that occurred in the way they constructed small houses (see Figure 2.2).

Ford: Culture and Continuity

Ford assumed that for cultural reasons, the Gamma-gamma people were constrained on possible house forms even if they could not articulate them. In accordance with Rouse's notion of a mode, Ford noted that house variation should be considered using dimensions/variables that had cultural salience by virtue of having a bounded range of values and

Figure 2.2: Gamma-gamma houses. Horizontal line is a dimension expressing the height of the house above ground. Vertical line is a dimension expressing a shape change from small, square houses to larger, rectangular houses, keeping the roof height approximately constant. Modified from Ford 1954: Figure 1



combination of values appropriate for these dimensions/variables. He noted that for the "ethnological observer it is quite clear that there is a Gamma-gamma house type with a mean and range of variation" (p. 47) or in statistical terms, the Gamma-gamma houses form a joint normal distribution (see Figure 2.2). Ford goes on to observe that it is not the houses that constitute culture, but that culture resides in "the aborigine's ideas as to the proper ways to construct dwellings"; the house artifact does not exist in isolation but reflects other aspects of the Gamma-gamma culture, such as monogamous marriage with married children setting up separate households.

At this point in his argument, Ford raised a question. Do the parameters (mean, variance, and covariance) that delineate the joint normal distribution that has been used to characterize the pattern of Gamma-gamma houses on the Island of Gamma have cultural validity? His answer is no: there is no reason to assume that the cultural concepts underlying the construction of houses are geographically limited to a single locality and a single point in time. If the pattern of variation in house form is space and/or time dependent—for example, there is an east-west gradient extending beyond the land of Gamma-gamma for the frequency with which one particular kind of roof is used—then the value of the parameters used to characterize house variation in the form of a joint normal distribution for Gamma-gamma is determined by the time period and geographic location for which house forms have been sampled. Parameter values estimated from the sample data cannot be used to characterize the normative values, say, of all the makers of the Gamma-gamma houses sharing the same culture. In brief, Ford argued that one cannot simply assume the spatial and temporal boundaries for sampling—especially convenience sampling—are also the spatial and temporal boundaries for cultural concepts.

Ford noted that simply selecting the sites to be excavated on the basis of convenience does not ensure that the space and time dimensions of artifact variability are adequately sampled. Consequently, "The fact that Site X was in a certain locality and represented a certain short span of culture history has determined the nature of the cultural types defined there" (p. 52). While the solution to the problem lies in valid statistical sampling of the spatial and temporal bounds for cultural constructs (Read 1975, 1986), the issue runs deeper than application of statistical sampling methods and poses the question of what constitutes the relationship between cultural concepts and artifact material produced in accordance with those concepts. The gradation of house form and stilt height in Ford's hypothetical example (see Figure 2.2) and the archaeological examples he cites (Milke 1949; Phillips et al. 1951; Ford 1952) raise the issue of whether the dimension in question is relevant to the identification of house types.

The horizontal dimension for the Gamma-gamma houses ranges from houses on the ground to houses on stilts; that is, there does not appear to be any restriction on the height of a house above the ground other than the physical limitation of the height of stilts, and even that is circumvented by constructing a house in a tree. In other words, any height value for this dimension is acceptable to the inhabitants of Gamma-gamma. The same occurs with the vertical dimension in Figure 2.2, though not to the same degree since even bigger or smaller houses could conceivably have been built in Gamma-gamma. These dimensions are not modes in the sense

discussed by Rouse since there is no culturally based, normative cultural value around which the house values are centered. Instead, all height values appear to occur with about the same frequency and so the house height values have approximately a uniform distribution. The mean value for this dimension is just a statistical construct without cultural meaning. In addition, the mean can shift without constraint; for example, we might find a change in the average height above ground as we move through time or across space.

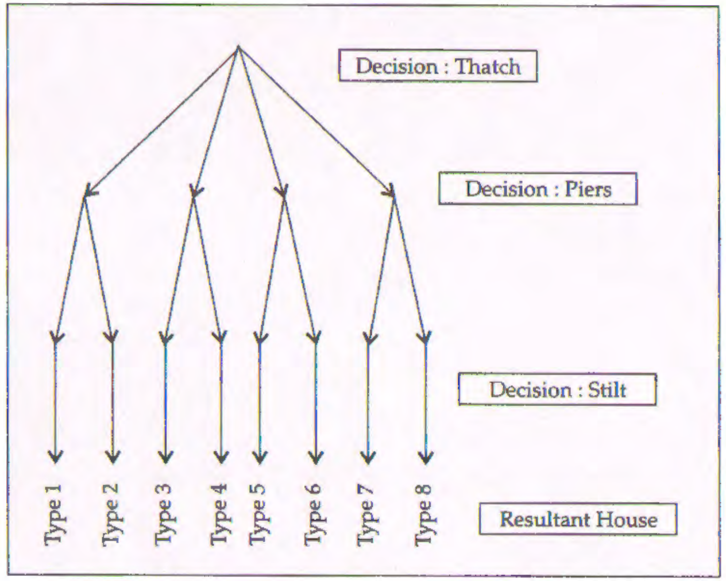
Ford refers to this kind of change as "cultural drift," but it is better described simply as drift since the dimension in question is the antithesis of a culturally salient dimension such as roof height. Unlike house height, roof height appears to be about the same for all houses even though (in reality) different roof heights are possible. The houses in the lower part of his diagram have disproportionately high roofs for the size of the house since roof heights do not vary with the size of the house. If this were a real example, we would want to know if the constancy of roof height across both a wide variety of house sizes and heights of houses above the ground is due to a cultural constraint on how roofs are built in Gamma-gamma. If so, roof height would be a culturally salient dimension and the mean roof height could be interpreted as an estimate of a normative value for roof height.

We will return to the notion of drift in attribute values through time in Chapter 10, where we critique the attempt to use the artifact equivalent of genetic drift as a distinguishing property for stylistic—as opposed to functional—variation in artifacts. Genetic drift and stylistic variability have been equated by archaeologists advocating a Darwinian evolutionary framework as a way to account for change in artifact properties through time. The houses in Gamma-gamma suggest to the contrary that drift relates to dimensions where there is neither functional nor cultural constraint, whereas a stylistic dimension occurs when the full range of feasible values is not implemented due to a cultural constraint on acceptable values for a dimension.

If we compare Ford's Gamma-gamma houses to Rouse's scheme for the production of artifacts using the two dimensions of stilt height and house size, houses are produced with a decision pathway for height and size values without any branches since there is but a single type of house (in terms of height and size) with considerable individual variability in dimensions such as stilt height and the size of the houses (see Figure 2.2). If we consider other aspects of house construction such as thatching, then we find that Ford allows for normative differences through there being "four standard methods of thatching" and different methods for making "anchor piers, to arrange plates, to lash rafters" (p. 47) in Gamma-gamma houses.

Though the Gamma-gamma houses were a fanciful creation on the part of Ford, nonetheless he highlighted a basis for making typological distinctions among the houses by introducing other dimensions that have discrete values in their instantiation through construction of a house. In Rouse's terms, for the latter dimensions there is a decision process that leads to different types of houses according to the decision made at each of the decision steps for making a house (see Figure 2.3, based on assuming four kinds of thatching and two kinds of house piers). As noted above, stilt height does not have any branches since the stilt height of a house is (apparently) an individual decision—though constrained by whatever is causing the east-west decline in house height—and variation in height does not correspond to different types of houses.

Figure 2.3: House types based on decisions about different methods of thatching, house piers, and stilt height



Ford also noted that there is no reason to assume that the space-time boundaries for one stream of ideas about houses (e.g., Figure 2.3) will be the same as for another stream of ideas. The presence of dimensions with different space-time boundaries is a theme that reappears in other contexts, such as when comparing the different spatial and temporal distributions of pottery depending on whether one is focusing on paste characteristics, pottery form, or pottery decoration. At the same time, Ford recognized the importance of statistical analysis for if certain of the features of the artifacts reflect a stream of ideas, then determining

whether several such streams of ideas were linked by the culture bearers "requires an analysis of the consistency of association of features which may, if necessary, be tested by statistical analysis" (p. 52).

Some of the concepts involved—such as the number of rooms in a house and how this relates to family cycles in terms of how many persons make up a household—are not determinative of other aspects of house form, such as the color of the roof or the material used to make the walls. The latter are part of what we can call the design of the house, and clearly some aspects of a design may vary one way with regard to time and space while other aspects may vary a different way in time and space, yet the underlying concept of a house as the physical location for the activities engaged in by family members may nonetheless be time and space invariant.

Krieger: Typological Method and Types

The important role that design plays in formulating a typology (Odell et al. 1996) is evident in what Alex Krieger (1944) called "the typological method," which he contrasted with classification as that term had been used by archaeologists. The latter, he commented, "consist[s] of balanced outline divisions. . . . For the sake of symmetry and ease in memorization, the headings and subheadings are usually carried out into a complete system of pigeonholes, whether or not specimens are found to represent all of them" (p. 275). Or in more technical terms, the classifications are presented in the form of a paradigm in which all possible combinations among the defining attributes—or divisional criteria—are constructed as possible types. Krieger's primary problem with classifications of this kind returns to the concern expressed by Rouse and others that, regardless of how one might choose to group artifact material, the groupings should reflect the conceptual system of the artisans and users of the artifacts and not simply be formulated for the convenience of the analyst.

Typological Method

It is worth quoting Krieger in some detail regarding his typological method, as it was not well understood by some of its critics. Krieger identified eight points of which the first four are the more relevant ones. His points 1, 2, and 4 relate to the basis for distinguishing types and his third point identifies the fact that formation of types leads to a taxonomy rather than a paradigmatic classification.

1. Each type should approximate as closely as possible that combination of mechanical and aesthetic executions which formed a *defined structural pattern* in the minds of a number of workers, who attained this pattern with varying degrees of success and interpretation (emphasis added).
2. Each type, with its probable variations, must hold its form with essential consistency wherever found. *Absolute* consistency is neither possible nor necessary for the analysis. With geographical spread of a type, slight alterations in the structural pattern inevitably occur.
3. Distinguishing criteria of type determination are not of constant value; what may serve to differentiate types in one circumstance may prove to be variation in another. The number of criteria needed for proof of clear distinctions may also vary with circumstances.
4. No matter how small the difference between specimen groups, these differences are of type importance if their distributions in space, time, and cultural association *are distinct* (emphasis added).

Though he does not reference Rouse, the similarity between Krieger's views and those of Rouse is clear. Rouse's use of a mode$_2$ as referring to the design aspect of the conceptual system/production systems underlying the production of an artifact appears here as "a defined structural pattern," and Krieger's following comment that it must be "in the minds of a number of workers" indirectly asserts that the pattern must be part of the shared/cultural domain and cannot simply be a structural pattern relevant to a single artisan. His comment about "varying degrees of success" and "essential" and not "absolute consistency" brings in the distinction between the structural pattern/design and its execution on the one hand, and the need for statistical analysis on the other. Similarity of artifacts as the consequence of one and the same "structural pattern" does not imply identity of artifacts with regard to their physical appearance.

Between the conceptual level of Krieger's structural pattern, which in Roger Keesing's (1974) terms is at the ideational—as opposed to the phenomenological—level, is the actual production process that may introduce other attributes into the artifact that are not part of the "structural pattern." Statistical analysis becomes relevant through the underlying assumption of a statistical model that variability in data values can be partitioned into two sources: model values and variation around model values. The model represents the cultural pattern executed without error, and the variation around model values represents deviation from the cultural pattern due to errors introduced during artifact production.

Krieger provided two answers to Ford's concern with space and time variation and cultural types. First, in the *execution* of a culturally specified structural pattern, space and time variation may reflect change

in the *instantiation* of the structural pattern rather than change in the structural pattern. Second, when there are discrete differences over time and through space, one has the basis for type difference. This implies that the spatial scale over which analysis takes place needs to be large enough to encompass boundaries to the distribution of artifacts produced in accordance with a particular structural pattern. Ford's Gamma-gamma house concept is not part of worldwide continuous variation in the structural pattern employed for the production of houses. Rather, it is a bounded system and when one moves beyond space and time coordinates relevant to that cultural system, a different set of conceptualizations about structural patterns and a noncontinuous shift in house form will also be observed.

This does not invalidate Ford's concern with the way in which recovery of artifact material may create the illusion of boundaries where in fact there is continuity. Instead, Krieger's comment makes it clear that attempts to find simple isomorphism between the actual grouping of artifacts on the one hand, and the conceptual pattern or design on the other, is a chimera—as argued later by Lewis Binford (1977) in reference to sets of artifacts used by modern-day Nunamiut hunters. A structural pattern need not be a literal blueprint for an artifact that includes precise instructions for its implementation, but may be a looser "pattern" in which some aspects need not be specified. For example, a potter might have in mind the structural pattern we refer to as a bowl. Even if there are normative aspects about the dimensions of the bowl—e.g., bowls should either be small or large in terms of a size dimension and shallow or deep in terms of a height dimension—the production of bowls satisfying these normative aspects will vary in the execution of the normative values; in addition, variation can occur in other aspects that are not normatively prescribed, such as the thickness of the sides of the bowl (though there may mechanical constraints on a thickness range if the bowl is to be used effectively). The mean thickness of the sides of bowls could vary in time and space for reasons having to with other conceptualizations that are operative in the making of pottery but are not part of the structural pattern of what constitutes a bowl.

With his third proposition, Krieger identified precisely the reason why procedures developed in biology under the rubric of numerical taxonomy are unsatisfactory. The numerical taxonomy methods assume that one can ignore variable selection by including all variables. But this will lead to divergence from, and not convergence on, groupings meeting Cormack's (1971) criterion of internal cohesion and external isolation—the generally accepted criterion for the grouping of objects, whether in biology or in archaeology (see Appendix).

Krieger did not lay out a methodology for implementing his view on typologies. Instead, he offered generalities such as the first step is to sort "specimens into major groups which *look as though they had been made with the same or similar structural pattern in mind*. This step is somewhat subjective. . . . The main point is to sort the material into groups which contrast strongly" (pp. 279–280, underlining added). His approach for the first step is reminiscent of what Adams and Adams (1991) refer to as sorting by a gestalt sense of pattern, except that in their scheme Adams and Adams had no goal at this stage in forming a taxonomy other than one of dividing a total collection into smaller groupings, each of which somehow hangs together—by whatever criteria—in the mind of the analyst.

Krieger's next step "is the breakdown of the working patterns according to differences which are seen to be consistent within some, but not all, of the specimens in each pattern. . . . This sorting will result in a large number of very uniform groups, each of which reveals but one specific combination of features" (p. 280). But Krieger is inconsistent: when he lays out the typological method, he only recognizes a type as representing a structural pattern. In this quote, however, he acknowledges a distinction between a structural pattern representing the features an artifact must have if it will satisfy the purpose or reason for why the artifact will be made and used, and the specified design for its implementation. Thus, in the case of pottery, he commented that specimens distinguished in the first step according to "both form and function"—which would make up the structural pattern that gives these specimens their commonality as a group—may in the second step be divided according to "details of neck shape and length, body curvature, base construction, paste, finish, etc., which are consistent through a number of specimens from one or more sites" (p. 280). Though he is inconsistent, the further elaboration he has provided in this discussion of a method has introduced essentially the distinction make by Rouse between a mode (viewed as a design = $mode_2$) and a type (viewed as the patterning of attributes = $mode_1$).

Types and Cultural Dimensions

Just as Rouse did not have an analytical means to determine what constitutes a $mode_1$ (let alone a $mode_2$!), Krieger also lacked adequate analytical methods for carrying out his typological argument and ended up with type descriptions that are essentially paradigmatic in form: each variable and its attribute states are listed for nominal variables, and for ratio variables the range of values is listed. He provided no information on the reason for the pattern—that is, the reason for the interactions among the variables. Nonetheless, he did recognize that the types are

not independent and there may be coherent groupings of types, which he refers to as a complex. The criteria for a complex is that "all types belong to a definite, delimited cultural configuration" (p. 282), but he does not specify what he means by a "delimited cultural configuration." Regardless, the use of a cultural dimension as the standard against which a system for grouping artifacts should be measured is clear in his comment: "Outline systems of classification [should] be abandoned for purposes of research in cultural relationships" (p. 286).

Placing the definition of types and the systematic organization of types under the broader goal of "research in cultural relationships" is central to the notion of archaeology as anthropology and simply reflects the fact that what we call "artifacts" are not a separate, isolated body of material in the lives of the artisans and users of artifacts that somehow are unrelated to the way in which we live in culturally constituted, conceptually bounded groups of individuals that we refer to as societies. Artifacts are produced in accordance with cultural concepts; they also provide a basis for the physical embodiment of cultural concepts as well as being instruments that are part of functionally motivated, goal-directed behavior (and sometimes simply reflect individual idiosyncrasies). Artisans make artifacts as part of a way to affect and modify the physical reality within which one lives, and in so doing commonality is established between *Homo sapiens* as a species with other species that similarly affect and modify their physical environment through objects manipulated or modified as a way to achieve what we can call functional goals. But we equally differ from other species in that artifacts are also part of the meaning systems that we refer to as culture and we form, construct, and make artifacts in accordance with meaning systems—whether the meaning be as mundane as "a vessel to hold liquid" or as complex as a "a sacred object that can protect against harmful forces."

To the degree that our understanding of the nature of culture is still imperfect, to that degree our attempts to relate artifacts to culture will be equally imperfect. Each of the authors discussed here has used notions and views of culture that can be criticized as insufficient, simplistic, or sometimes even erroneous. But more to the point, each has taken seriously the notion that artifacts do not simply come into existence, but are produced in the context of a cultural system(s) and are therefore part of culture—even if the linkage to culture is primarily at the conceptual level through the conceptual framework that underlies the production of artifacts (as Rouse assumed), or is more directly linked to culture through the assertion that culture must necessarily be physically expressed (as recently argued by Roy D'Andrade [2002]). From this perspective, the notion of what constitutes a type, what constitutes the relationships of types to each other, and how several types should be organized in a systematic manner, must be in agreement with our understanding of how cultural systems are formed, organized, change, vary, and so on. But not all archaeologists share this viewpoint. In their book *Archaeological Typology and Practical Reality*, Adams and Adams argue that type definitions and typologies are ways to organize artifacts for practical reasons and so are only constrained by our definition of what constitutes a typology.

Adams and Adams: Practical Typologies

Whereas Krieger (1944) rejected classifications as procedures for forming groups with an uncertain relationship to the cultural/conceptual system underlying the production of artifacts, Adams and Adams (1991) defined a typology as a special kind of classification. A typology is "made for the *sorting* of entities" (p. 47, emphasis added) whereas a classification can be made without this purpose in mind, though once a classification is constructed, it can be used for sorting entities. This idea of sorting carries over to types since "A type, unlike other kinds of classes, is also a sorting category" (p. 47). From this distinction between a classification and a typology, they derive several consequences. First, the "boundaries of the systems as whole must be clearly specified" and the group of entities to be sorted must be well specified. Second, the set of types must be exhaustive: each entity must be assignable to one of the types. And finally, the types must be mutually exclusive, which means "we have to invest our type categories with sharp boundaries *even though no such boundaries may be discoverable empirically*" (p. 47, emphasis added).

In more formal and set theoretical terms, they are viewing the sorting process as one of constructing a partition over a set of entities, and so the partition then determines an equivalence relation over those entities. An equivalence relation over a set S of entities is a relation R defined over S (i.e., a list of ordered pairs of entities from a set S of entities) that is (1) reflexive—i.e., $x\mathrm{R}x$ (read "x is related to x") for all entities, x, in S; (2) symmetric—i.e., if $x\mathrm{R}y$ is true for the elements x and y in S, then $y\mathrm{R}x$ is also true; and (3) transitive—i.e., if $x\mathrm{R}y$ and $y\mathrm{R}z$ are true for the elements x, y, and z in S, then $x\mathrm{R}z$ is also true. Any relation R that satisfies these three conditions will partition the set S over which the relation is defined into disjoint and mutually exclusive subsets called equivalence classes. For an equivalence relation, entity x is equivalent to entity y if, and only if, entities x and y belong to the same class in the partition determined by the equivalence relation.

A typology, according to Adams and Adams, is the partition formed by constructing an equivalence relation over the set of objects that will then be used for placing the objects into their respective equivalence classes. Since any partition of a set of objects into mutually exclusive and

disjoint subsets determines an equivalence relation, then according to their definition any partition of a set of objects is a typology so long as one actually uses the partition to sort objects. Under their construal of a typology, Brew's notion of needing to make many typologies has reached its logical extreme. A new typology can be constructed simply by forming a partition of the collection of objects and then sorting the objects according to that partition. The number of possible partitions of a set grows rapidly with the size of the set; for example, a set of size 10 has 115, 975 possible partitions (Weisstein 2006).

To their credit, Adams and Adams also take into account the purpose of the archaeologist as a way to distinguish from among all possible typologies those typologies that are of interest. Most of the astronomically large number of typologies that are possible according to their definition are not of any particular interest, except perhaps as an academic exercise in forming a partition of a group of entities. To reduce the number of potential typologies, Adams and Adams provide the criterion that any partition is valid so long as it satisfies some purpose. But this is a very loose criterion for, as they comment, "there is surely no typology in existence that serves no purpose at all" (p. 52). If so, the criterion of "having a purpose" does not provide much guidance about how to form a typology.

Gestalt Approach to Typology Formation

In fact, Adams and Adams do not take their definition of a typology as providing a methodology for how to proceed. Instead, they refer to the capacity of our brains to find patterning—what they refer to as a gestalt process of pattern identification: "When we examine our initial collection of material, it is likely that a few intuitive types will 'jump out at us' in the form of intuitive gestalts. These are clusters of objects so distinctive that we are sure immediately that they must be significant" (p. 53). While there is a superficial similarity to Kreiger's first step of determining a group of entities that seem to arise from a structural pattern, Adams and Adams place no constraint on what constitutes a gestalt sorting; and so if the sorting is to have reference to the cultural context in which the artifacts were produced, then we must share—or at least be able to identify—the same gestalt as the makers of the artifacts. This, however, is not plausible.

To see the problem with their argument, consider Hardin's (1984) comparison of how Tarascan and Zuni potters have a radically different conception of whether a vessel has a design as a whole or whether it is based on configurations within the overall design. She comments, "Zuni potters . . . sort pictures of whole vessels into groups, which is something Tarascan potters will not do. . . . Zunis think of their pottery in terms of ideal types" (p. 584) whereas for the Tarascans, "their classificatory framework was a multidimensional system of pigeonholes" and they "base their organization of design information on design configurations" (p. 583). When the analyst considers Zuni and Tarascan vessel designs, does he or she intuitively realize the different bases upon which these designs are formulated and how these affect the notion of what constitutes similarity in design? Hardin does not think so; she suggests that debates among archaeologists about classifications "may thus be resolved as matters of ethnographic variability" (p. 587). If the analyst does not intuitively form gestalts that correspond to the bases upon which the artisan produces designs, the resulting typology is simply our cultural product and hence does not have scientific standing as an ordering of artifacts that can be mapped into the context of the culture of the makers and users of the artifacts.

Adams and Adams reject the possibility of universal gestalts (p. 42), which implies that the sorting is based on gestalts that are a product of our own culture and experiences. They comment, "[G]estalts can be acquired as well as intuitive. Types that we have originally determined through a process of conscious analysis acquire a gestalt when we have learned to recognize them at a glance. . . . [O]ur types have in some sense become 'real' *to us*. . . . [T]ype gestalts, whether intuitive or acquired, are a practical necessity in large-case sorting operations" (p. 54, emphasis added). But surely our "intuitive gestalts"—the ones we know about from our experiences—are not the basis for forming types, for then we have precisely the problem that they find with the approach advocated by Rouse, Brew, and others. But that approach, argue Adams and Adams, ends up incorrectly equating functional types with emic types.[3] Yet "functional types" can also be part of the intuitive gestalts and so if functional types ≠ emic types, it follows that "intuitive gestalts" ≠ emic types; i.e., the typology simply becomes our classification of their material objects according to our cultural perceptions. One way out of this dilemma, they argue, is for the intuitive gestalts to become "acquired gestalts" based on a "conscious analysis." But what constitutes that conscious analysis? Adams and Adams do not discuss this crucial point for their argument.

They do recognize that the "types disclose[d] to us in the form of gestalts" (p. 54) can be subjected to elaboration once enough "intuitive types" have been assembled. At this point, the analyst supposedly can begin to determine the basis for the similarities and dissimilarities among the intuitive types and eventually, they suggest, the focus of the analysis will shift to the basis for dissimilarity among tentative types and thereby the "types acquire the important dimension of set-membership" (p. 54); that is, one can now construct a partition for the set of artifacts.

But the dissimilarities are in terms of how we perceive gestalts, and the methodology for forming types and a typology becomes an exercise in working out our intuitions about similarities and dissimilarities among a group of objects without having any theoretically based potential pattern as a basis for evaluating the validity of a proposed typology. They suggest that finding the basis for dissimilarities "provides a basis for the recognition of new types that did not disclose themselves though gestalts" (pp. 54–55). Purpose comes in, they suggest, as the differentiation proceeds even though the initial gestalts "are usually unaffected by any conscious sense of purpose" (p. 55), for the differentiation "becomes more rational and systematic" since "purpose increasingly dictates the choice of variables and attributes to be considered in type formulation" (p. 55).

Typology Validation

Adams and Adams presume essentially that one's intuitive ability to discern "self-evident" groups will converge on a more systematic typology as experience makes clearer which distinctions are useful or meaningful in terms of the archaeologist's goals. But will two archaeologists with the same goals arrive at the same typology? Does the initial choice of a tentative selection of types on the basis of intuitive gestalts affect the form of the resulting typology? If choice of variables and refinement of groupings is inevitably part of the formation of a typology, what criteria should be used? Questions of this kind are not addressed. Indeed, something as fundamental to a scientific enterprise as validation does not appear to play a significant role in their framework.

Apparently, there is no validation criterion a typology must meet other than forming a partition that can be used for sorting. Rather than needing a way to validate a typology, Adams and Adams suggest that for "the typologist[,] 'reality' is measured simply in the satisfactory attainment of his objectives" (pp. 55–56), but what constitutes "attainment of objectives" is not spelled out. Instead, one depends on a "natural selection" of individually satisfactory typologies that arises via the degree to which a typology becomes widely accepted and part of scientific discourse.

It appears that Adams and Adams are confounding a relatively explicit description of how one of the authors developed a typology for Nubian pottery with an implicit method for validation of a typology. The authors discuss how the practitioner was engaged in a learning/dialectical process and how one's understanding of the patterning in the material being analyzed increases with one's experience with that material. This is hardly surprising; that a proposed typology is subject to change and is not immutable had been discussed in detail by Brew a half-century before

Adams and Adams cover essentially the same ground. What Adams and Adams assert is that the kind of differentiation that goes from obvious differences to more refined distinctions could not simply be done with the procedures of, for example, numerical taxonomy. They comment that "differentiation is of course the basic principle in many computer-generated taxonomies, which are formulated by continuous stepwise partitioning," and the only difference between the computer-generated taxonomies and the gestalt-based procedure that they advance is that their procedure "is rarely that consistent or that automatic" (p. 55).

In their framework, one cannot determine if a procedure such as numerical taxonomy produces valid taxonomies since their basic criteria of forming a partition over a groups of objects for the purpose of sorting them is satisfied by the methodology of numerical taxonomy. Undoubtedly, archaeologists such as Hodson who have advocated the use of numerical taxonomy procedures (Doran and Hodson 1975) would find that what these procedures produce are "individually satisfactory typologies." Others, though, are less sanguine about automatic classification procedures.

Adams and Adams do reject taxonomies generated through clustering procedures, but mainly for reasons that demonstrate lack of understanding of those procedures. Their primary concern seems to be that "types are the beginning point in normal or intuitive taxonomies, in computerized taxonomies made by splitting they are the endpoint of the taxonomic process" and so "they have none of the flexibility and adaptability of ordinary type concepts" (pp. 206–207). A closer perusal of Doran and Hodson's (1975) discussion of numerical taxonomy methods, and in particular a clustering procedure known as *k*-means clustering (SPSS 2003), would have made it evident that flexibility and "learning" are certainly possible in a numerical taxonomy approach. And whether one first works out the types and then arranges them hierarchically in a taxonomy, or first establishes the taxonomy and then works downward to the types, is formally the same. There are, however, serious problems with the procedures lumped under numerical taxonomy (as will be discussed in Chapter 5); but discerning those problems requires that one has some criterion for what constitutes a satisfactory typology when dealing with artifacts (or organisms), and not simply a formal criterion independent of any theory regarding how the domain in question is structured by order-producing processes.

Types of Typologies

The absence of any connection between the process of constructing a typology and theory about how the phenomena in question arose

through order-creating processes allows Adams and Adams to construct a typology of typologies and purposes for typologies in which each type of typology is treated as if it is a kind of typology independent of other kinds of typologies. They distinguish the following kinds of typologies or classifications: (1) phenetic—focus on material properties; (2) stylistic—ethnic and cultural identification; (3) chronological/spatial—space/time systematics; (4) functional—recover activities of users; (5) emic—"Understand mind-set of makers and users" (p. 216); and (6) "cultural"—classification of cultural units. The fifth kind of classification is further elaborated as representing typologies for which "the types designated by the archaeologist can be presumed to reflect some intention on the part of the makers" and one type is different from another "because the makers intended them to be different" (p. 223). If a typology formulated on this basis is a different kind of classification than, say, a stylistic classification, then presumably a stylistic classification uses criteria for differentiation of types other than "intention on the part of the maker."

But where does the differentiation come from? Surely, Adams and Adams are not arguing that the analyst should make distinctions such as arbitrarily dividing a continuum into two parts and treating the parts as if they are differentiated by a criterion that, allegedly, represents stylistic differences? Their "intuitive gestalt" begins with "obvious differences" regardless of the final purpose of the typology. But those "obvious differences" had to come from somewhere, and for artifacts the presumption is that the differences came about by the actions of the artisans who produced the artifacts. If so, then the differences—even if we call them stylistic, functional, or cultural differences—are a consequence of the perceptions of the artisans and the concepts, ideas, designs, and the like that guided the artisan in his or her production of an artifact; that is, the differences identified by one's "intuitive gestalt" are presumably differences that had salience to the makers and users of the artifacts. In Rouse's terms, the "intuitive gestalt" must be keying in on differences among modes (in the sense of mode_1) and the analyst is mentally distinguishing between modes and attributes at an intuitive level. This is precisely the kind of distinction that cannot be done in the context of numerical taxonomy methods. If the "intuitive gestalt" does not distinguish between modes and attributes, then the method advocated by Adams and Adams simply becomes a way to implement the methods of numerical taxonomy through physical sorting of artifacts, rather than the numerical taxonomy method of sorting artifacts based on measurements made over the artifacts.

With item (5), Adams and Adams have also, in effect, set up a "straw man" by relating emic to "understand[ing] the mind-set of makers and users."

Ultimately, that is a pointless goal—both because of the impossibility of doing so in any serious way, and because it improperly defines "emic" via a psychological rather than cultural criterion. Emic, in the form introduced by Marvin Harris (1968), has to do with cultural saliency—not psychological validity—and contrasts with etic as having scientific saliency. While not precisely the meaning the terms had when they were introduced into linguistics by Kenneth Pike (1967), the emic/etic distinction can be viewed as a distinction between two conceptual systems: the conceptual system of the culture bearers and that of the analyst who is attempting to identify (to the extent this is possible) the conceptual system of the culture bearers.

The distinction has been very useful and much needed. It is in the sense of emic versus etic that Rouse formulated his difference between mode_1 and attribute, with a mode_1 being an attribute where one had evidence for cultural saliency. The methodology proposed by Adams and Adams of beginning with an "intuitive gestalt" (for our goal as anthropologists of shedding light on cultural and adaptive systems through artifact material) only makes sense when the "intuitive gestalt" keys in on an emic pattern whose expression is sufficiently obvious that we can recognize it despite our using an "intuitive gestalt" predicated upon our own cultural context. Adams and Adams' notion that the types become "real" to the archaeologist only makes sense if with experience the archaeologist begins to understand the emic patterning, just as an ethnographer begins to understand the cultural milieu in which he or she is a participant/observer. Otherwise, it becomes a form of archaeological imperialism in which the archaeologist assumes that his or her "reality" superimposed over the cultural reality expressed in the artifact material produced by societal members provides insight into their cultural reality even though one is using divisions foreign to them.

It is certainly possible to differentiate among the goals an archaeologist may have according to what he or she is trying to elucidate. It follows that, depending on one's goals, one can focus on different aspects of the artifact material and thereby might make fewer or more distinctions; but whether one focuses on modes that are said to be "stylistic" or modes that are said to be "functional" (or satisfy some other criterion), the underlying methodology for making types and typologies is no different: types represent patterning among a set of modes and a typology is a way of showing the relationship of types to each other based on the modes used to distinguish the types. When the focus is primarily on style, the emphasis will be on what appear to be the stylistic differences that were salient for the artisans and users of the artifacts; and for such a study, one might temporarily ignore "functional" modes even though—from

an emic perspective—such a separation may not have had culturally validity. A similar conclusion holds for a "functional" analysis. We can call these a "stylistic typology" and a "functional typology," but what we mean by so doing is reflected in our choice of modes that are being used to construct the particular typology, not that we have different types of classifications (as if these are conceptually different ways of making a typology). In effect, Adams and Adams have elevated a typology of how archaeologists carry out their work, such as one archaeologist focusing on stylistic aspects of artifacts and another archaeologist focusing on functional aspects of artifacts, as if this is equivalent to saying something about the conceptual relationship between the task of forming types and typologies and the goal of carrying out the anthropological study of past societies.

Intuitive Sorting

Adams and Adams provide other characteristics of types beyond initially identifying them through "intuitive gestalts." Here, however, we will only identify some of the problems that arise from their emphasis on the practice of sorting artifacts and inferring types in lieu of considering the structural patterns involved in the production of artifacts by artisans in accordance with the underlying conceptualizations made by the artisans. Adams and Adams assume that object grouping (the consequence of identifying "intuitive gestalts") and attribute clustering as discussed by Albert Spaulding (but mistakenly considered by Spaulding as equivalent to type definition, as will be discussed in Chapter 4) are ultimately identical to each other (p. 60). They also comment, "[T]he relevance of any particular type, for the *purposes* of its typology, is usually not in any way proportional to the number of its members" (p. 79, emphasis added).

If attribute clustering and object clustering are essentially two ways to achieve the same goal, and if frequency counts are not relevant to object clustering, then it follows that frequency counts are not relevant to attribute clustering. However, attribute clustering is based on the frequency of types and is not equivalent to object clustering. Consider the following simple example. Suppose that pottery artifacts are being made by two groups of artisans and both groups share the same modes. Suppose there are two modes: temper (with two values: sherd and sand) and surface treatment (with two values: polished and not polished). Suppose that the artisans making up Group 1 independently decide on the value for mode 1 independently of the choice made for mode 2. Suppose Group 1 makes pottery with frequencies similar to those shown in Table 2.1.

Table 2.1: Group 1 Pottery

		Surface Treatment	
	Modes	Polished	Unpolished
Temper	Sherd	28	12
	Sand	42	18

From the viewpoint of object clustering and intuitive gestalts, we would consider pottery made by Group 1 as consisting of four types: (1) sherd tempered/polished, (2) sherd tempered/unpolished, (3) sand tempered/polished and (4) sand tempered/unpolished. In addition, it might be the case that these four combinations correspond to four shapes of pottery items, or they could correspond to differences in time and space location of the pottery. From the viewpoint of attribute clustering, however, since the two dimensions are independent as indicated by the frequency counts (that is, the proportion of polished to unpolished pots is the same for sherd tempered and sand tempered pots and the proportion of sherd to sand tempered pots is the same for polished and unpolished pots), there is no patterning among the attributes making up the two modes and so there is a single type of pot.

Table 2.2: Group 2 Pottery

		Surface Treatment	
	Modes	Polished	Unpolished
Temper	Sherd	5	35
	Sand	55	5

Now assume the pottery produced by Group 2 has frequencies as shown in Table 2.2 where we have the same four object clusters as for the Group 1 pots, but the pattern of differences in frequency counts in the cells implies that there is patterning to the way in which the modes are associated. For whatever reason, two of the object cluster types are not commonly made by the Group 2 potters and two of the object clusters are commonly made. Whereas the variables temper and surface treatment are independent in Group 1, they are not independent in Group 2; thus, these variables are associated, implying that there is patterning among the attribute states for these two variables. Since we have patterning among the attributes, we should be able to identify types based on that patterning. When we try to do so, however, there is ambiguity in how we should interpret the fact that the two variables—temper and surface treatment—are associated.

The association between the variables temper and polish implies that at least one pair of the attribute states making up the possible combinations

of attribute states for these two variables is nonrandomly associated. However, neither which pair (or pairs) of attribute states is considered to have a nonrandom association is clear cut, nor how types relate to these pairs of attribute states. We can account for the nonindependence of the two variables in several ways. It may be that the combination, sand tempered/polished, has occurred much more frequently than would be the case if the two variables are independent, or it might also be that both that pair and the pair, sherd temper/polished, occurred more frequently than would be the case if the two variables were independent. If we decide on the latter possibility, should sand tempered/polished surface pots and sherd tempered/unpolished surface pots be considered as two types, or do they jointly comprise a single type? Both interpretations are consistent with the lack of independence between the two modes. Should the low frequency counts for the other pairs of attributes be treated as different from zero only for a statistical reason such as "sampling error" or "measurement error"? or do the low frequency counts simply indicate that some types were not used frequently?

We will discuss this interpretation problem in more detail in Chapter 5. For the moment, it suffices to note from this example that differences in the frequency of pots made by Group 1 versus Group 2 does affect our decisions about possible types and object clustering and attribute clustering methods need not lead to the same types.

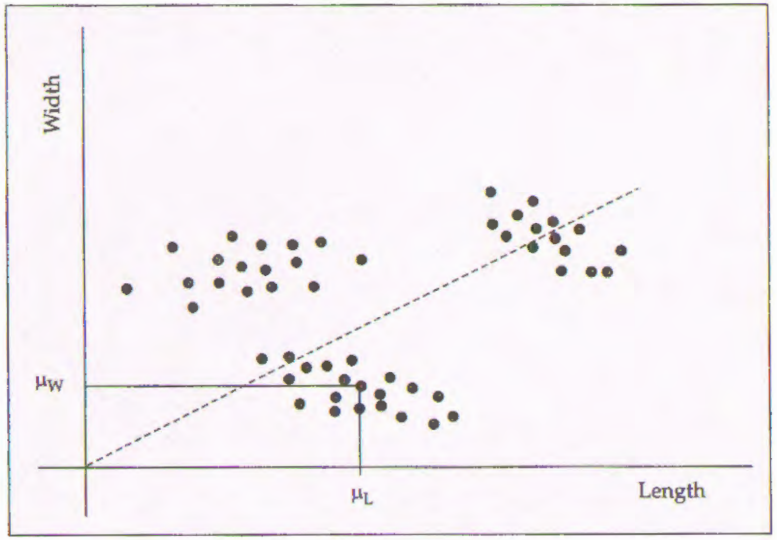
Attribute clustering, defined as statistically significant association of variables having those attributes as variable values, depends on the frequency distribution of objects in the paradigmatic classification. In contrast, object clustering based on attribute combinations for discrete variables does not depend on frequency counts. However, the frequency counts are relevant to interpretations that might be made of the object clusters. The frequency counts indicate that the frequency of use for the objects in a type can be quite different for one type in comparison to another type.

Adams and Adams also reject the notion of types being based on quantitative measurements when considering archaeological materials. While it is true that many variables of interest are qualitative, especially for pottery artifacts, it does not follow that "archaeological types . . . cannot be derived from one another by processes of quantification or measurement," or that "the only role that quantitative measurement ordinarily plays in the formulation of basic types is in determining whether a particular group of attributes . . . occurs together with sufficient frequency so that they can be thought of as collectively defining a type" (pp. 88–89). Dunnell also makes a similar comment: "No kind of quantitative information may be used in definition [of types] because units cannot be created utilizing continuous 'attributes'" (Dunnell 1971: 54).

These comments ignore the fact that not only can types be defined using parameter values for quantitative measures; some types can only be defined using quantitative measures.

For example, suppose we have two quantitative measures such as length and width and three groups of artifacts as displayed in Figure 2.4. The three groups are instances of three types of artifacts. However, no simple discrete variable can be formed from the values for length or width that would allow us to either distinguish these three groups from one another or to express the co-variation between length and width in each of these groups of artifacts. When we consider length for these three groups, we have continuous variation from small to large values and similarly for width. Nor are the three groups separated by differences in shape. A shape ratio variable (see dashed line) for the upper right group neither characterizes the shape of the objects in that cluster nor distinguishes it from the other two clusters as indicated by the intersection of the dashed line with the lower, center cluster.

Figure 2.4: Three clusters of artifacts. Dashed line: *W/L* = shape ratio for upper right cluster. Solid lines mark the location of the mean of the parent population for the lower, center group



Nonetheless, we can define types for these three groups by considering each group to be a sample from a population of artifacts of the same kind and then characterizing this population by using statistical parameters. For example, the lower, center group can be characterized as a sample of artifacts from a population with mean centered at (μ_L, μ_W), dispersion

given by (σ_L, σ_W), and covariance between the two variables given by σ_{LW}. The dispersion measures the extent to which the variable values differ from the (population) mean value for that variable and expresses the degree of spread among the points making up a group. The covariance measures the extent to which the values obtained for the two variables tend to co-vary and expresses the elliptical shape and orientation of that group of points.[4] Sample measurements computed over a group of artifacts can be used to construct estimates for these parameter values.

While it is useful to present both the way in which one has worked out a typology for a group of artifacts (Dunnell 1993) and attempt to make more explicit the "dialectic" between forming types and arranging types in a taxonomy, along with the learning and decision processes that are involved, one is left with the impression that in the final analysis, type formation and typology construction—according to Adams and Adams—is simply an art and hence we are dependent on our trust in the skills of the person who has done the classification. Other than making more explicit the steps involved in intuitively sorting artifacts and formulating types, Adams and Adams contribute little to developing methods that can link the process of forming types, typologies, and taxonomies to the general theoretical goals of archaeological anthropology (Dunnell 1993). If anything, they see a contradiction between the two since, in their view, "theory has led where practice could not follow" (p. 311). While it is true, as they note (following Scriven [1958] and Levin [1973: 391–392]), that "classification and other conceptual and measurement devices do not constitute theory," their criterion that "the ultimate test is . . . whether they work for any particular purpose" (p. 312) ignores the fact that a typology and a classification can only elucidate effectively aspects of past societies if in fact the phenomena in question are structured in time and space by the analyst in accordance with conceptual systems that related the interests, intents, goals, and the like of the artisans and users of artifacts to the production of artifacts.

An artifact typology can be useful for space-time systematics only because of the way in which conceptual systems underlying the production of those artifacts are variable in time and space. Artifacts are not somehow imbued with characteristics that vary in time and space independent of the cultural context in which they are embedded. While it is true that typologies "are a necessary starting point for the development of theory" (p. 313), that starting point can only be a good starting point to the extent and degree to which our current understanding of the relationship between cultural systems and the material objects that are part of those cultural systems are explicitly used to guide the methods by which we identify types and construct typologies and taxonomies. The "intuitive gestalt" only "works" because the phenomena are already structured in a sufficiently strong way that despite the passage of time and change in cultures, we are still able to recognize the differences in artifact form introduced by artisans through their instantiation of their conceptual systems in the material form we refer to as artifacts. It is surprising that Adams and Adams do not want to explore why the intuitive approaches have worked and whether one can elaborate upon them and arrive at even more meaningful organization of artifact material than can be done through reliance on "intuitive gestalts." The earlier writers on typologies clearly had this goal in mind, as can be seen from the typologies that they created—the topic of the next chapter.

Before turning to that topic, we need to consider briefly the program for archaeological systematics introduced by Robert Dunnell (1971) in his book *Systematics in Prehistory*. Though not widely cited, the book has had substantial impact on our thinking about the goals of type definition and typology formation through his elaboration on the difference between group and class as a difference in analytical levels and his argument that classification is the basis for unit formation central to scientific reasoning.

Dunnell: Archaeological Systematics

Class Definitions, Culture, and Units

Dunnell makes explicit the distinction between a group at a phenomenological level (that is, a group is a collection of material objects and group properties are summations of the properties of the objects making up the group) and the ideational level of a class (that is, a class is a concept; hence, a class is part of the domain of ideas and class properties may be abstractions such as attributes that determine class membership).[5] Types are classes, not groups, and a descriptive definition of a specific group of artifacts cannot be part of a type definition since that definition will change with change in group members. Instead, we make type definitions such as "decorated" or "not decorated" pottery since the concept "decorated" is not determined by specific instances of pots with decoration and its meaning does not change when a pottery object is added to, or removed from, a group of pottery objects subsumed under the "decorated pottery" class.

Properties of artifacts at the phenomenological level and types at the ideational level are linked through culture: "*Prehistory assumes that attributes which are the products of human activities and which recur over a series of artifacts . . . can be treated as manifestations of ideas held in common by makers and users of those artifacts*" (Dunnell 1971: 132).[6] The ideational domain to which one refers when forming a type definition must be that of the makers and users of the artifacts and not our own system of ideas.

The type in question will be defined etically using our concepts such as "decorated pottery" since we do not have access to the conceptual repertoire of prehistoric, and even historic, artisans. Nonetheless, according to Dunnell, the type that is being distinguished must represent a concept or distinction that was part of the cultural repertoire of the makers and users of the artifacts. For this reason, types are defined using modes (in the sense of Rouse's $mode_1$) and not attributes and so a "type is . . . *an intuitive cultural class of discrete objects*" (p. 128). When we add the role of classes as the basis for forming units, we arrive at Dunnell's basic framework: artifacts are embedded in culturally salient classes that provide the basic units for delineating how the cultural/ideational domain is mapped onto the phenomenological domain, thereby providing "explanation of artifacts in cultural terms" (1971: 128).

Equating types with units assumes that there is a quality or property common to the objects brought together in the class, and the variation that may occur at the phenomenological level of individual objects is ignored in favor of the property representing each member of the class. To continue with the example of a "decorated pottery" class based on pottery surface decoration, variation in how the decoration is applied (color of paint, quality with which the decoration is executed, designs used in the decoration, etc.) is ignored when the pottery object is just considered to be a member of the class "decorated pots."

At the phenomenological level, we might distinguish individual pots and even individual potters (Hill 1978) by aspects of the decoration. However, when we say that a pot is a member of the class "decorated pottery," we are suppressing individual characteristics in favor of a property shared in common across all pottery included within this class. Of course, the class "decorated pottery" might be subdivided into subclasses to the extent that subdivision is warranted by identifying variation among individual pots that is not simply idiosyncratic and appears to be culturally or functionally mediated variation. The justification for suppressing individual characteristics, according to Dunnell, lies in linking the class with the cultural domain of the artisan. An artisan, for example, does not simply make material objects but makes material objects in accordance with shared concepts about materials that will be used, techniques that will be employed, and sequences of production steps to be followed.

Those aspects of the process of artifact making—whether it be pottery, lithic, basketry, or whatever—that are based on shared concepts provide the quality or "essence" identified in the class definition, when that definition succeeds in identifying properties embedded on the artifacts by the artisans in accordance with their shared concepts. We identify the class "decorated pottery" by virtue of the fact that it appears to us through our analysis (which might include the kind of gestalt-based sorting discussed by Adams and Adams [1991]) that artisans shared the concept of decoration as part of making certain kinds of pottery objects. Hence, the class "decorated pottery" becomes our etic way of recognizing a conceptual distinction shared by the artisans in the manufacture of pottery objects. Once the class is identified, the individual object loses its importance and instead it is the class that becomes our primary unit of measurement. The class, "decorated pottery," has become a unit, possibly along with its opposition, "not decorated pottery."[7]

Dunnell's view of archaeological systematics outlined above has been critiqued for his assumption that the goal of archaeology is to understand how behavior in the context of culture leads to the properties of artifacts rather than the other way around (Shenkel 1973). However, his notion of types as representing class distinctions in the ideational domain of the users and makers of artifacts can be viewed as either providing units relevant to understanding how behavior in the context of culture leads to properties of artifacts, or as providing units relevant to understanding the cultural domain through behavior. In either case, the key notion is one of types constituting units for the domain of discourse.

Implicitly, if not explicitly, the notion of artifact types as units is well established in instrumental typologies (such as pottery or lithic typologies) constructed for the dating of sites. The underlying rationale for the types that are distinguished in this kind of typology stems from the claim that a type has an associated calendrical time period independent of spatial location, and so evidence for the presence of a type in an archaeological assemblage provides a way to date the site to that time period. The type is thus taken as a unit with a time reference. The individual pottery object found in a site is not dated directly, as would be the case with dating techniques such as radiocarbon dating. Instead, the pottery object provides evidence for the pottery type in question being part of the repertoire of the potters inhabiting that site and so the site must date from the time period associated with the pottery type.

Paradigmatic Classifications

Class definitions may be formed by first determining relevant dimensions and discrete values for each of these dimensions. Each possible combination of the discrete values—one from each dimension—becomes the definition of a class, and the collection of classes so defined becomes a paradigmatic classification system. The example given above regarding temper and surface treatment has the form of a paradigmatic classification system, with four classes corresponding to the four ways in which the

two states for each of the two variables (temper and surface treatment) may logically be combined together.

A paradigmatic classification defined in this manner may have classes without representatives for the data set being analyzed. For example, if we have a third group of potters making pottery corresponding to Table 2.3, and assuming the 0 value for the combination sand tempered/polished surface is not due to sampling error but represents the lack of any pottery being made with this combination of attribute values, then only three of the four paradigmatically defined classes are relevant to the pottery made by Group 3.

Table 2.3: Group 3 Pottery

		Surface Treatment		
	Modes	Polished	Unpolished	Total
Temper	Sherd	28	12	40
	Sand	60	0	60

When an entire dimension is not relevant to some of the material being classified, then we will have a taxonomic rather than a paradigmatic classification. For example, some pottery—such as corrugated pottery from the American Southwest—does not have surface treatment. For pottery like this, the dimension "surface treatment" is not relevant. Suppose the pottery without surface treatment always has sand temper. In tabular form, we would now have two cells with 0 as the entry value (see Table 2.4), but this violates the usual convention that all of the entities in question are included in the cells making up the table. For this reason, taxonomies are usually displayed in a hierarchical manner based on set inclusion using a branching diagram that displays the basis for dividing a higher-level category into subcategories (see Figure 1.4).[8]

Table 2.4: Group 4 Pottery

		Surface Treatment		
	Modes	Polished	Unpolished	Total
Temper	Sherd	28	12	40
	Sand	0	0	60

Dunnell misleadingly presents type definitions as being defined paradigmatically: "[A] type is defined as *a paradigmatic class of discrete objects defined by modes*" (1971: 157). Some types may be defined in this manner; others cannot, as shown in Figure 1.5. In addition, it is not the

choice of the analyst as to whether a typology aimed at identifying cultural units should have the form of a paradigm or a taxonomy. Rather, the structure for the classification, contrary to claims made by some researchers for the primacy of paradigmatic classifications (e.g., Odell 2001; O'Brien and Lyman 2003), will need to reflect the way modes were mapped onto artifacts by the artisans or morphological differences were introduced through use—for example, unretouched flakes (Read and Russell 1996).

The lithic types distinguished for lithic tools used in the Western Desert of Australia provide an example of types that do not form a paradigm (see Figure 1.4). Not all of the dimensions relevant to at least some of these lithics are dimensions relevant to all of the lithics. The fact that not all dimensions are relevant to all of the artifacts implies that a dimension relevant to only some of the artifacts either cannot be the basis for a measurement system applied to all of the artifacts, or may have values that obscure a distinction that applies only to some of the artifacts. The *purpunpa* lithics discussed in the introduction were nominalized either as small (adzes) or large (choppers) by the Western Desert Australians, as shown by a bimodal distribution for the size of the *purpunpa* lithics, but the large/small dichotomy does not apply to the *tjimari* (knives) lithics. Hence, in a collection of Western Desert lithics that initially contains—unbeknownst to the analyst—both *tjimari* and *purpunpa* lithics, a size measure for the collection as a whole may not display bimodality if the size of the *tjimari* fits between the small and large *purpunpa*.

In the next chapter, we consider how these ideas about types and typologies, ranging from the features of artifacts to the structural form of a classification, have been implemented for classification of pottery from prehistoric societies of the southwestern United States. The different viewpoints about the goals, purposes, and forms of typologies expressed by the writers considered in this chapter are reflected in the different ways pottery typologies were being constructed. The issues that arose reflected not only arguments about what constitutes types and typologies, but also differing viewpoints about forming classifications that can incorporate the complexity and variety of pottery artifacts that were being recovered by archaeologists, yet are also designed to meet the goal of forming classifications that provide insight into the social and cultural systems in which pottery production was embedded.

3

Pottery Typologies

Introduction

In 1957, a group of southwestern archaeologists met at the Pecos Conference at Gila Pueblo in Globe, Arizona, to address the growing problem with the proliferation of pottery types. At this meeting, they developed what is now known as the type-variety system for pottery analysis (Wheat et al. 1958: 34, note). The proliferation of types was due to archaeologists finding it necessary to form more precisely delimited types "in order to localize in time and space the infinitesimal variants of pottery which constitute, with other aspects of material culture, the documents of regional prehistory" (Wheat et al. 1958: 34). The authors recognized that the problem with the ever-expanding pottery typologies was not due to the number of types that could be distinguished, but with their lack of organization. Types, it was argued, are "representative of cultural phenomena" (Gifford 1960: 341); hence, the formation of types by the analyst should reflect and be guided by the complexities of the social and cultural system in which the pottery production was embedded.

Southwestern prehistoric societies were complex and so it is not surprising that pottery, as a material whose final form is only loosely constrained by the form of the raw material, should also be complex with regard to the relationship between pottery objects and the cultural systems in which artifact production and use was embedded. From this premise, it follows that if our categorizations are to reflect the cultural systems of the artisans, the organization of types delineated by the analyst should be determined through methods sensitive to culturally guided processes of pottery production. Though the analyst constructs types and typologies, their definition and organization are constrained by analytical goals. As argued by the participants at the Pecos Conference, these goals may include identification of the categories and relations among

categories salient for the makers and users of the pottery objects. Types identified by the archaeologist, if they are to be sensitive to aspects of culture, cannot simply be independent constructs with no interconnection other than what has been introduced by the analyst. This goal, however, was not always followed in practice. As Martin et al. noted with regard to the phases defined on the basis of pottery types: "We realize that a phase is an artificial and chronological system superposed on man-made materials . . . phases are merely arbitrary culture groupings set off in arbitrary units of time"(1952: 30; quoted in Olson [1962]).

It was widely accepted by the developers of the type-variety system, in parallel with Rouse's arguments (cf. Colton 1941: Chapter 5), that pottery objects were distributed in space and time in ways that reflected how cultural systems were distributed in space and time. But even more, Gifford argued that the sequence going from raw material to the conceptual organization that underlies the production of artifacts "is an analytical progression from the specific to the general, from percepts to concepts, and in this case from appreciable examples of human behavior (in pottery making) to concern with abstract cultural elements" (p. 344). Gifford relied upon Kroeber and Kluckhohn (1952: 155) for the distinction between behavior—which may or may not be produced in accordance with cultural concepts—and those cultural concepts underlying some aspects of behavior, and saw that archaeological analysis could parallel ethnographic analysis wherein culture "is an abstraction from concrete human behavior, but it is not itself behavior" (Kroeber and Kluckhohn 1952: 155, as quoted in Gifford 1960: 345). Gifford, as if anticipating the subsequent argument about archaeology as anthropology, recognized that the formation of classificatory systems along the lines of the type-variety system "can be used in various ways to increase our understanding of cultural processes" (1960: 345).

What is called the "type-variety system" is actually composed of several components that vary from the more concrete to the more general. The proposed system elaborated on by Gifford identified five key constructs: (1) variety; (2) type (Colton and Hargrave 1937); (3) ware (Hargrave and Colton 1935; Colton and Hargrave 1937); (4) sequence (Colton 1953); and (5) series (Colton and Hargrave 1937). But more important than being a way to organize the types identified by southwestern archaeologists was the attempt to ground these constructs in arguments about the form and nature of cultural systems on the one hand, and how this relates to the production process by which the artisan begins with raw material and ends with a finished object on the other. The key construct in this organization is the type serving as the dividing point between what

Rouse referred to as the idiosyncrasies of the individual artisan versus the community "standards" that are part of the cultural systems in which the makers and users are embedded.

Pottery Type

In a paper published in 1960, Gifford elaborated on the notion of a type as it had been discussed by Colton and introduced several distinctions that expanded on Rouse's basic idea that a type is a pattern of modes. Though Rouse was not always consistent in his usage of the term mode as discussed in Chapter 2, the idea of a type as a pattern of modes has the implication that a type is a pattern discovered—rather than created—by the analyst (Smith 1954); that is, just as a mode is an attribute that had cultural saliency, a type must be a pattern of modes that arose in a cultural context. Gifford's elaboration focused on two aspects: the notion of culture as shared and the notion of culture as constructed through social interaction. Gifford viewed a type as the realization by the artisan, via a "mental image" and his or her "motor habits' "in such a away that when executed in clay, they fulfilled the requirements of the ceramic and *stylistic values of that culture*" (p. 342, emphasis added). Thus, while the potter produces an object, the potter is also producing an object that is an instance of a type (as opposed to simply a pottery object) only when what is produced satisfies a set of conceptions that are part of the cultural domain of a community. It is the "mapping" or "embedding" of the object into a cultural conceptual system that makes the object an instance of a "type," not simply the behavior of the artisan in making an object and not simply the fact of having made an object. The conceptual system is "cultural" by virtue of it being a shared conceptual system; hence, it also has spatial coherency by virtue of being simultaneously shared across spatially distributed individuals and temporal coherency by virtue of being transmitted between individuals across generations.

The importance of the social context was made explicit in Gifford's comment that "[a] type is regarded as being the material outcome of a set of fundamental attributes that coalesced, consciously or unconsciously, as a ceramic idea or 'esthetic ideal'—the boundaries of which were imposed through the value system operative in the society *by virtue of individual interaction on a societal level*" (p. 343, emphasis added). So although an individual artisan may produce pottery objects, the object that is produced takes on a cultural aspect when produced in accordance with ceramic values/ideas that are not just shared but have developed in a social context of interaction. The latter is important since it distinguishes among concepts that might be shared for a variety of reasons, including coincidental sharing via similar patterns of individual learning, imitation of individuals with high status, and so on, and separates from these the concepts that are shared through social interaction to serve as the basis for defining a type.

Accordingly, not all clay objects produced by the potter are instances of types, and not all instances of types are necessarily without significant variation. The notion of a type as an object produced according to a "ceramic idea" does not preclude the potter from making objects that do not adhere to this criterion; they are artifacts but they are not types of artifacts. Similarly, though several artisans making similar objects through imitation may superficially satisfy the "shared concepts" aspect of culture, Gifford suggested that in addition to "shared concepts," the social interaction through which the concepts became shared was critical for the concepts to be part of culture. While it might be objected that artisans who imitate one another are also engaging in "social interaction," Gifford was obviously referring to something more than simply a sociogram or a network analysis that provides a measure of the extent to which there is social interaction. The "something more" is the elusive aspect of social interaction in which what arises out of the interaction is not simply a summary measure of how many individuals share the same ideas (i.e., the extent to which there is consensus), but an aspect that has been referred to variously as cultural rules, cultural models, schemas, conceptual structures, ideologies, and the like—that is, to a conceptual system that has coherency across individuals, both horizontally and vertically, and a system that is not simply the summation of the concepts held individually.

Not all archaeologists accepted the idea of linking types with culture as their rationale. Other archaeologists contemporary with Gifford—such as Philip Phillips—assumed that "the primary aim of ceramic taxonomy is to facilitate the daily operations of archaeology, such as stratigraphy and seriation" (Phillips 1958: 121), a view reiterated three decades later by Adams and Adams (1991) as discussed in Chapter 2. Though Phillips viewed taxonomy as a means to facilitate the dating of sites and strata within sites, he shared Wheat et al.'s (1958) view on the status of a variety in a taxonomic system and suggested an improvement of the definition of a variety that was incorporated later by Gifford.

The notion of a variety had previously appeared in Colton and Hargrave's work on forming a classification of southwestern pottery as a way to handle variants that appeared to be due to the idiosyncrasies of individual potters (Colton 1946, 1952), but the idea of a variant did not have a formal status in Colton and Hargrave's classification scheme. Rather, Colton and his coworkers used the idea of a variant informally as a way to decide when differences in pottery objects should be considered a type difference based on the criterion that a type difference implied

the variants displayed either geographical or time difference (Colton 1952: 1). One of the goals held by the organizers of the 1957 Pecos Conference was to give the variety a more formal status in a taxonomic system.

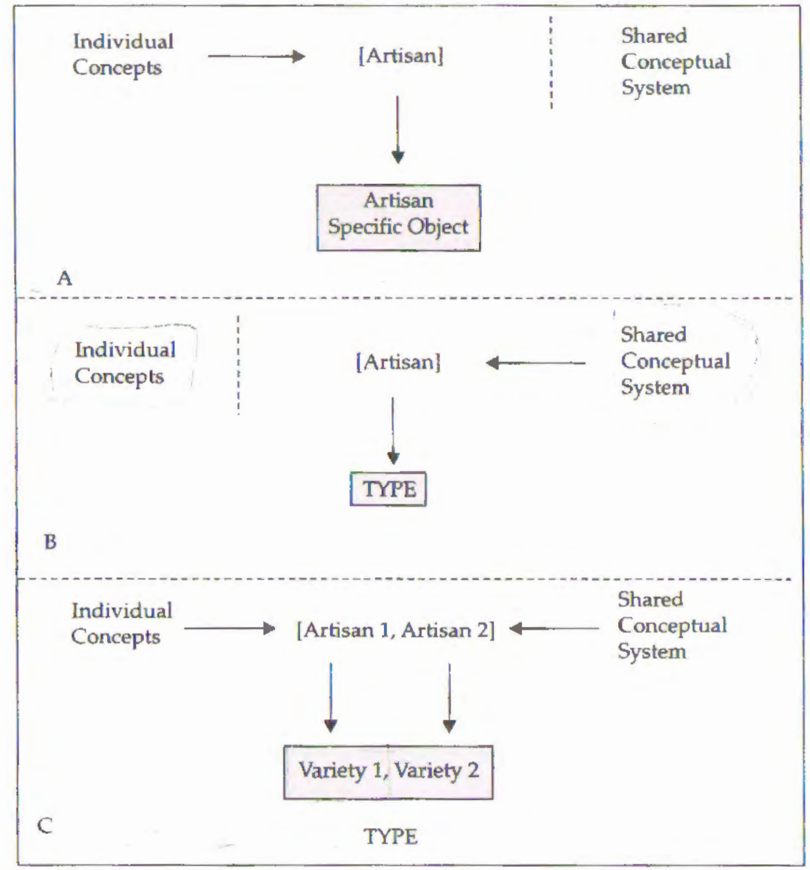
Phillips contributed to this goal by suggesting that a type should be construed as the set of varieties, each of which was consistent with the same cultural pattern but differed from each other in aspects that did not have cultural saliency. In contrast, Wheat et al. had previously considered a type and a variety to be comparable, except that a type was in some sense more representative of the cultural pattern than a variety. How one would determine which variety is more central was not spelled out; nor is it clear what saying that one variety is more central meant. Did this mean that the maker and users of the pottery would perceive one variety as the preferred variety, or was centrality simply a concept imposed by the analyst? Phillip's modification of the relationship between a type and a variety made the issue moot. In the next section, we will make the difference between these two views of a variety and a type more precise.

Pottery Variety

For those objects that fail to satisfy the type criterion, Wheat and his coworkers introduced the concept of a variety. While a "rough and ready" notion of a variety might be that a variety is a variation on a theme, more was being implied. For Gifford, "[v]arieties are apt to reflect 'individual and small social group variation' rather than whole-culture phenomena, while the type portrays a combination of a number of pottery traits that were acceptable not only to the potter but to most *others adhering to a given culture pattern*" (Gifford 1960: 343, emphasis added). This implies that a "'variety' is a reflection of concrete individual human behavior while a 'type' represents an abstraction from individual or small social group behavior that is the ceramic unit most useful in showing relationships of one kind of pottery (one ceramic cultural element) to another" (p. 345).

We can represent these various ideas about types and varieties as in Figure 3.1, Boxes A-C. In Box A, we illustrate the case where the artisan only draws upon his or her concepts about the object and does not incorporate concepts that are part of a shared conceptual system about what constitutes appropriate pottery technique, form, and design. The objects that are produced are artisan specific. In the middle box, we illustrate the other extreme of an artisan drawing only upon the shared conceptual systems, and in this case the artifact is an instance of a type. In the third box, both individual and shared concepts are brought to bear, thus making the objects that are produced by different artisans members of a type

Figure 3.1: Contribution of individual and shared concepts to artifact production: (A) only individual concepts; (B) only shared concepts; and (C) combination of individual and shared concepts



by virtue of being made in conformance with the shared conceptual system. At the same time, individual concepts may become part of artifact production but in a different manner from one potter to another (Nicholson and Patterson 1985: 234; Stark 1995: 249). Nonetheless, regardless of the variation among artisans with regard to individual concepts about the production of an artifact, the shared conceptual system provides commonality across the variations that arise from differences introduced at the level of individual artisans. Hence (and in accordance with Phillip's [1958] definition), a type is represented by the collection of varieties and is not one of the varieties singled out as the supposed central type among the collection of varieties produced under the same conceptual system.

At first glance, it might appear that the introduction of a variety into the classificatory systems makes more explicit Rouse's view of an artifact as being the result of both types and modes on the one hand, and noncultural factors on the other. In Rouse's terms, the type "outlines the limits within which the appearance of an artifact can vary" (1939. p. 18) and thereby "prescribes the alternative features which an artisan can apply to an artifact and still have it remain in style [= type]" (p. 18). But the latter includes factors such as chance, individual quirks of the artisan, physical capacities of the artisan, and potentialities of the environment (1939, p. 19). Not all of these would be subsumed under the concept of a variety, yet they are responsible for some aspects of the pottery object. In addition, what is specified jointly by the artisan's concepts about a pottery object—and the shared concepts that are the basis for defining a type—is not a blueprint for making a pottery object, but relates to patterning in those aspects of the pottery object as a whole that can be attributed to the instantiation of these concepts. The shared conceptual system makes it possible for individuals to agree on whether the object produced by the artisan is a valid instance of what they collectively perceive are the boundaries for the form, shape, decoration, and so on, of a pottery object for it to be considered an appropriate pottery object even though there may be variation in other aspects of the pot: "Examples of a particular kind of pot could be judged appropriate by both makers and users and yet vary in several aspects" (Stark 1995: 233).

The type and variety concepts only capture a portion of the features of the complete pottery object. Those portions of the pottery object that connect, link, or provide the material basis for those features that represent shared concepts are also aspects of the pottery object.[1] For example, a shared concept might be that certain kinds of jars will have a single handle, but the specific form and size of the handle may be free to vary according to the artisan's perception of what should be the form and size of a handle. Or the artisan might have a specific concept for what constitutes a handle form, but the specific size of the handle consistent within some size range may be different among instances of producing jars with a single handle. The size of the handle would neither be a mode arising from the shared concept of a jar having a single handle, nor an attribute arising from the artisan's concepts about handle form, yet the size of the handle is part of the representation of the jar as an object and the range of variation in this measurement over different objects may reflect the extent to which there is standardization in the production steps involved in the production of a pottery object (Costin and Hagstrum 1995: 3).[2]

We can characterize the pottery object as a whole, then, as being made up of those features or aspects arising from instantiation of the shared concepts (type features), those features or aspects arising from instantiation of concepts held by the artisan (variety features), and those features or aspects that arise during the production of the object for any other reason (object features): pottery object = type features + variety features + object features. Implications of this characterization for the analysis of features will be discussed in Chapter 8.

The type-variety system thus assumes that two conceptual systems are involved in the production of artifacts: (1) concepts and ideas that are specific to an artisan and (2) shared concepts and ideas that are part of the cultural system. These concepts and ideas come together in the conceptualization by the artisan of a particular artifact, which means that more abstract concepts become more concrete via the variables through which a design can be expressed. There are thus two sets of variables, with one set corresponding to the individual concepts of the artisan expressed on the artifact—that is, those aspects of the artifact whose attributes are produced in accordance with the part of the design that corresponds to the concepts specific to the artisan—and the other set corresponding to the aspects that arise through implementation of the conceptual system via a design. The artisan produces an artifact/object in accordance with this conceptual/design system and we can refer to the production process as a means by which the underlying conceptual system(s) is (are) instantiated in the form of concrete objects. The object that has been produced can be decomposed by the analyst—through doing what Rouse referred to as analytic classification—into those attributes arising from artisan specific concepts and those attributes (modes) arising through the conceptual system. The type can be described via the patterning of the modes—what Rouse referred to as taxonomic classification.

The problem with distinguishing between attributes and modes can be addressed, in part, through one of the implications of the type-variety distinction. The distinction suggests that the distribution in space and time of varieties (that is, the distribution of attributes as opposed to modes) should be on a scale smaller than the distribution of cultural elements when the spatial scale over which interaction among artisans (hence the opportunity for noncultural sharing of individual concepts) is smaller than the spatial scale for social interaction that relates to cultural boundaries. Obviously, implementation of this distinction is not trivial since it requires an independent measure for the distribution of cultural elements other than the purported type or variety. Formulating such a measure is not implausible, though, since the distribution of cultural elements relates to the extent to which social groups—such as the groups

making up a settlement system—share cultural concepts, and the latter relates to the social organization of a society and how that social organization is distributed over settlements. For example, small villages in patrilineal societies tend to be made up of a single lineage of males plus in-marrying wives, whereas settlements in matrilineal societies may be larger and composed of several lineages or portions of intermarrying lineages (Keesing 1975). Under these conditions, varieties should be more evident in patrilineal than matrilineal systems when the potters are females.

Types as Groups of Varieties

The type-variety system, with the modification proposed by Phillips, views a type not as a class term for a single homogeneous group of pottery objects, but as a term that may refer to several such groupings. Each of these groupings corresponds to a variety, and since a variety has a feature that distinguishes it from other varieties, varieties are based on objectively different groupings. If different varieties are not different types, then each variety must be distinctive at the level of attributes and not modes.

Though it may not have always been made explicit, the type-variety distinction only makes sense if one accepts Rouse's distinction between a mode and an attribute and his corollary that a type is defined in terms of modes. However, from the viewpoint of the artisan, the variety is as "real" as the type since the artisan must implement attribute and modal values equally. Further, regardless of whether the artisan perceived a difference between modes and attributes, the variety relates to the full set of concepts—individual and shared—brought to bear in the production of a pottery object, as indicated in Box C of Figure 3.3. None of the varieties is composed purely of modal patterning; hence, none of the varieties can be distinguished as being "the type." Thus, a type properly becomes a covering term for a collection of varieties (and the collection can consist of just a single variety) that are produced, keeping constant the shared concepts activated in the production of a pottery object.

Grouping of Types: Ware, Series, and Sequence

Pottery Ware

If a type refers to several varieties, where the commonality across the varieties relates to the cultural level of patterning expressed in terms of modes, then one can equally ask whether several types can be grouped

together in a culturally meaningful way. For the members of the Pecos Conference, the pottery ware was one such possibility: "A 'ware' is a large *grouping* of pottery types which has little temporal or spatial implication but consists of stylistically varied types that are similar technologically and in method of manufacture" (Wheat et al. 1958: 35, emphasis added). But previously Colton had stated that a ware was a conventionalized grouping of types: "Wares do not exist. A pottery ware is a conception. . . . Although a ware is not a reality it is a convenience that aids us in our thinking" (Colton 1952: 2). In part, Colton's insistence that a ware is an etic—rather than an emic—category may have been influenced by the explicit use of a Linnaean classification system for pottery in which a type was equivalent to a species and a ware was equivalent to a family and a genus was defined by surface treatment (Hargrave 1932: 8). The shortcomings of that edifice, however, were made evident in Brew's rejection of an analogy with biology as a basis for archaeological classification.

In practice, though, a ware was used in a different way and referred to the properties of the paste used to make a pottery object—such as the kind of temper used in the paste and the color of the pottery surface after firing (Hargrave 1932)—in keeping with Guthe's definition of a ware as "a ceramic group in which all attributes of the paste and the surface finish remain constant" (Guthe 1927). Thus, wares were described in terms of the properties of the material from which a pottery object was made—that is, the paste and its color, not the types supposedly encompassed within the concept of a ware (as one would surmise from Colton's comment). In addition, the properties that distinguished a particular ware, such as gray paste, sand temper, and white surface color, were also included among attributes used to distinguish a type. But if a ware is supposed be a group of types, then the types cannot be defined using the criteria for the grouping of types without the concept of a ware as a group of types becoming vacuous.

Colton attempted to maintain a distinction between a ware as an etic category and a type as an emic category (to use more recent terms that express the distinction that concerned him) by saying that a ware had the status of being a conception devised by the analyst because it was based on "basic methods of manufacture," whereas a type referred to "details such as styles of painted design" (p. 2); and so the type had reality for the artisan. The distinction seems contrived, especially in view of his comment that "a daughter learned her art from her mother" (p. 2). What the daughter learned was the method of making a pot, the kind of temper to use when preparing the clay, and how to fire the clay; that is, she learned to use only certain values (e.g., a particular kind of sand or ground sherd) out of the range of possible values for

the temper added to the clay. To the extent that other artisans shared the same notion of the appropriate range of values for the variables in question, the ware was just as much based on a shared set of concepts as the type. That Colton and his coworkers could distinguish about thirty wares, each with its defining characteristics and each having distinct time and space distributions, can only mean that a ware is the analyst's recognition of shared patterning imposed by artisans on the properties that clay material should have in order for the clay to be suitable for making pottery objects.

Unlike lithics, where the material properties are largely fixed once choice of raw material has been made, pottery making also involves modifying the properties of the raw material from which a pottery object will be made. Water is added to give the clay the desired consistency and temper is mixed with the clay to ensure the clay has the desired properties when fired. By varying the temperature and controlling whether the firing will be an oxidizing or reducing process, the color of the clay after firing could be controlled by prehistoric potters. These transformation processes are as much sources for patterning in pottery attributes as the design details cited by Colton that give the type its emic reality.

Though the collection of types grouped together on the basis of similarity in the paste from which the pottery object is made constitute an etic construct, Colton erred by trying to make the collection of types the definition of a ware—rather than viewing the pottery objects included in the types as constituting a collection of objects constructed from paste that satisfies the definition of a ware. The grouping of types in this manner is an etic construct since the grouping will likely have a distribution over space and time that crosscuts meaningful cultural boundaries. To make an extreme example, grouping together all artifacts made of clay regardless of an object's location in time and space may be useful for analytical purposes (e.g., pottery versus lithic analysis), but the grouping, "all pottery objects," does not have any inherent emic validity since it crosscuts a variety of shared conceptual systems separated in time and space.

For a grouping of types to have cultural relevance, the grouping has to take into account three dimensions pertinent to the presumed cultural underpinnings for the production of pottery: cultural variation as expressed in the different pottery types that are distinguished; differences in the geographical distribution of concepts related to one pottery type in comparison with another; and differences in the temporal longevity of concepts among pottery types. The participants in the Pecos Conference attempted to develop a scheme for forming groupings of pottery types that allegedly had cultural saliency. Two of these groupings were a pottery series and a pottery sequence.

Pottery Series and Pottery Sequence

A pottery series "consists of technologically related pottery types which are similar in decorative technique . . . the constituent types of a series occur with a definable geographical unit without exact limitation in time" (Gifford 1960: 35, based on Colton and Hargrave 1937: 3; Colton 1955: 2). In contrast, a sequence "carries a connotation among its constituent types of evolutionary development. A ceramic sequence is composed of pottery types similar to each other in decorative style and other manifestations, which have evolved, one from another, from early to late times" (Gifford 1960: 35, based on Colton 1953: 75–78; see also Gallus 1977). In the first definition, geography is critical and in the second definition the primary dimension is time. However, what is meant by "evolutionary development" for a pottery sequence is not specified.

As "supra-type" groupings become broader in scope, the connection of the grouping to cultural criteria becomes more tenuous and depends increasingly upon less obvious assumptions about how the concepts of which a culture is comprised are distributed across space and through time in accordance with the location of individuals holding these concepts. Further, different types have different spatial and temporal trajectories; hence, their corresponding cultural concepts have different time and space trajectories (where, of course, 'space and time distribution of cultural concepts' is a shorthand way of referring to where the culture bearers of those concepts were located in space and time). Rather than providing a means to neatly organize the growing corpus of types that were being distinguished by southwestern archaeologists, one ended up with a complex edifice (e.g., Wheat et al. 1958: Figure 3) whose cultural reality was problematic. The problem was not so much in the goal, though, as in a classification system that did not come to grips with the complexity of the materials that were being organized through the classification system. In particular, the way in which pottery is inherently a multidimensional production process was not adequately addressed by the way the basic unit in the classification system (a type) was distinguished.

Pottery Production

The definition of a pottery type developed in southwestern archaeology reflected the steps involved in pottery production, but did not take into account that pottery production is based on the conjunction of several conceptual systems relating to different stages in the production of a pottery object. Pottery production can be divided into at least the following sequence of steps: selection and preparation of raw material/clay; technique for working clay (hand, wheel, coil, etc.) into the desired form;

surface treatment of the clay (no special treatment, polishing of the surface, application of a slip, etc.); choice of a form for the pottery object; choice of decorative design (if any) to be applied to the pottery object; means of applying the decoration (engraving, affixing clay elements, painting, etc.); choice and application of appendages (handles, etc.); and firing.

A type description simply included each of those steps as an attribute: type of temper, core color, mode of construction, properties of vessel walls in terms of strength, surface finish, surface color, form of vessels, paint, pigment, design, and mode of firing (abstracted from Colton 1952). Though most of these attributes have pottery-specific values, form was typically specified through the range of forms that might be produced, keeping the other attribute values fixed. Quantitative measurements appeared to be added as an afterthought. In some cases, the range of wall thickness for a form such as a bowl might be provided, but in other cases no metric dimensions were given. Surface finish was sometimes described in details such as "interior surfaces fairly well smoothed, with scraping marks barely noticeable" (Colton 1952: 25), which clearly included features simply reflecting the skill of the artisan when using a scraping method for smoothing the clay. In short, the type definitions seemed to be ways to express what appeared to be the basis for differences that had become apparent to the researcher through familiarity with the corpus of materials; that is, the type definitions had more the character of expressing the basis for the "intuitive gestalts" (to use Adams and Adams' phrase) that led the researcher to distinguish pottery groupings, and less the character of definitions derived on the basis of an underlying theory of how cultural concepts become instantiated in the form of the artifacts produce by the artisans.[3] As noted by Dunnell, "They were literally *descriptions of pottery assigned to a particular type*, not definitions of the type" (Dunnell 1986: 165).

The outline of a theory for pottery classification was not lacking and had been articulated in a number of ways by archaeologists (such as those in the Pecos Conference group) writing about classification and the relationship of pottery types to the cultural context in which artisans produce pottery objects. In its simplest form, the theory argued that the artisan acted in accordance with shared concepts about acceptable modal patterns, where the modes represented those aspects of an object that were culturally constrained in the way they could be instantiated in the object produced by the artisan. At the same time, other aspects of the object that were not culturally constrained—and thus reflected individual potter concepts—are also part of the pottery object, as indicated in Box C in Figure 3.1. What has been lacking is adequate analytical means to implement this theory.

The complexity that arises with pottery (in comparison to lithic) classification stems from differences in the properties of the raw material used for making pottery versus stone lithics. The clay used by the potter allows for an additive, rather than a subtractive, process (Green 1982). The "units" of the material (i.e., clay particles) are sufficiently small and pliable in aggregated form so that one can deform an initial mass of clay into virtually any desired shape and range of possible sizes. The characteristics of the raw material that enable the production of form also allow for the surface of the object being produced to be given characteristics that are not simply the consequence of the procedure used to produce the desired artifact shape. In contrast, lithic artifacts—at least prior to the introduction of grinding techniques used to smooth the surface of stone tools—have a surface with characteristics that primarily reflect the technology used to produce the desired form of the lithic artifact. As a result, pottery surfaces can be the foundation for pottery decoration, thereby introducing another dimension to the characteristics of pottery objects. And yet another dimension relevant to the ware concept concerns the physical characteristics of the clay, both in terms of clay characteristics introduced during the making of a pot and the characteristics introduced through the drying and firing of a pot that converts the clay into a rigid form—including color changes induced through the firing process by chemical changes taking place in the clay.

Production Stages

Rather than viewing pottery production as a linear sequence of steps, we can consider it in terms of production stages that relate to the selection and preparation of raw material/clay, techniques for working clay (coil, wheel thrown, etc.), modes of surface treatment (no treatment, polishing, application of a slip, etc.), choice of form, choice of decoration (if any), application of decoration (engraving, affixing bits of clay, painting, etc.), choice and application of appendages (handles, spouts, etc.), and firing (oxidizing, reducing, etc.).[4] In this sequence, we can distinguish four conceptually independent operations involved in the production of pottery objects: (1) the production steps that are responsible for the properties of the material from which the pottery is made; (2) the production steps that relate to the form of the pottery; (3) the production steps that relate to the surface of the pottery; and (4) the production steps that relate to the decoration of the pot, if any.

The first dimension includes production steps that affect the properties of the paste such as choice of clay, kind of tempering material, and properties induced in the clay through firing in accordance with the

temperature of the kiln—including whether the firing is done in an oxidizing or a reducing atmosphere. The second dimension incorporates the actual technique used to produce a pot, such as coiled pottery or wheel-thrown pottery, and the form that is produced by the artisan from an initial mass of clay—including appurtenances that might be applied to the pot (such as handles) or modifications made to the basic shape (such as a rim or a spout). The next dimension relates to the characteristics of the surface of the clay introduced both by the mode of production and by whatever finishing may be done to the surface by the artisan, such as smoothing the coils of the pottery object or polishing the surface. The fourth dimension relates to the decoration that may be applied to the pot, either through incising or otherwise modifying the surface of the pot or by applying a design to the surface through paint or other coloring medium. Each dimension can be viewed at two levels, the ideational and the phenomenological, with each level involving a transformation from an initial state to a final state for a relevant dimension (see Figure 3.2).

Property Transformation

At the phenomenological level, the property dimension has a series of transformations beginning with the properties the clay when it is obtained as a raw material to the properties of the clay when it has been made into a finished pottery object (see the sequence of property changes in the lower part of Figure 3.2). These changes include not only more evident changes—such as temper added to the clay, the consequences that firing the clay has for the physical characteristics of the fired paste, and the color produced through the firing—but also changes in the properties of the clay induced through other dimensions such as polishing, which brings fine particles of clay to the surface and thereby makes a less water permeable surface (Schiffer 1990b).

Correspondingly, at the conceptual level, we may consider a transformation of the *conceptualization* made of the raw clay properties—denoted "<properties>" in the upper left part of Figure 3.2—to those properties of the modified clay recognized as relevant to the production and usage of pottery in the cultural context of the artisan and denoted as "Properties_1" in Figure 3.2.[5] The overall transformation has been divided into two parts, T_{P_1} and T_{P_2}, in accordance with the fact that physical changes at the phenomenological level occur both at the beginning and ending stages of pottery production. The first transformation, T_{P_1}, refers to transformations regarding how the properties of the raw material are conceptualized and then modified in accordance with the corresponding transformation at the phenomenological level (bottom part of Figure 3.2). The second transformation, T_{P_2}, refers to material changes in the clay due to firing; at the conceptual level, T_{P_2} links the prior conceptualization, Properties_1,

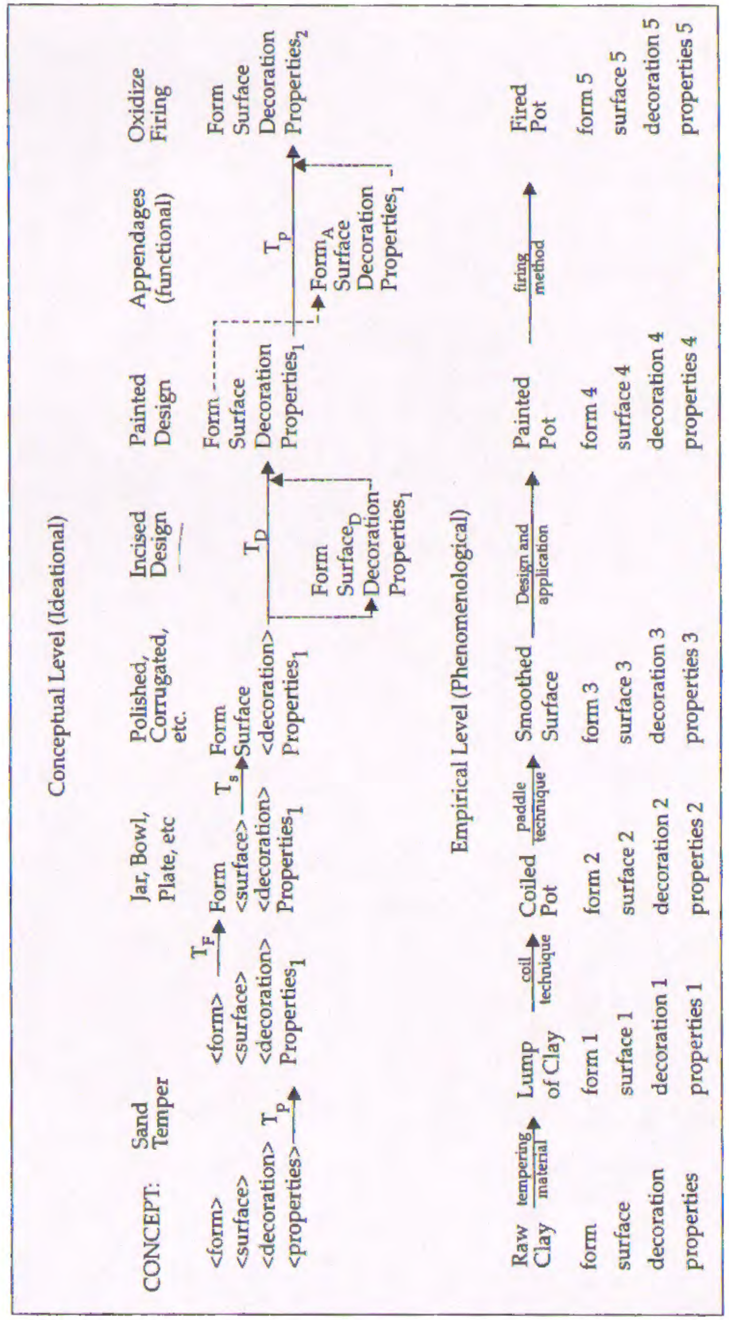


Figure 3.2: Linkages between the conceptual and empirical levels in pottery production

to the subsequent conceptualization, Properties$_2$, of those aspects of the changes in the clay due to firing that are recognized by the artisan. An example of T_{P_2} would be deliberate use of a reducing atmosphere when firing the pottery if some of the properties arising from a reducing atmosphere—such as the color of the paste after firing—were part of the artisan's conceptualizations about pottery objects.[6] At the same time, there may be other properties that arise at the phenomenological level (bottom part of Figure 3.2) that are not "recognized" by the artisans, such as a "carbon streak" in the clay after firing (Colton 1952: 7) and so are not part of Properties$_2$.

Form Transformation

The second dimension (at the conceptual level) involves a transformation, T_F, from the form exhibited by the mass of clay from which the pottery object will be built to the form of the clay as conceptualized by the artisan (either in a manner unique to the artisan or as a form that is part of a cultural context) and denoted "Form" in Figure 3.2. An additional transformation, T_A, occurs for Form when appurtenances or appendages (such as handles, spouts, etc.) are physically added to the pot form and represent a conceptual transformation of the basic form of the pot (see dashed lines, right side of Figure 3.2). The appendages differ from a similar process of adding additional clay to the pottery object as part of its decoration through the appendages being functional (in the sense of affecting the efficacy of using the pot for certain tasks such as carrying the pot or pouring liquid from the pot) rather than stylistic.

Surface Transformation

The third dimension involves a transformation, T_S, beyond the properties of the surface that result simply from working the clay into a pottery form. Any working of clay affects the surface characteristics of the clay. By surface transformation is meant the characteristics of the surface of the pottery object introduced by the artisan that are not necessary for the production of the pottery form, such as occurs with polishing of the clay surface. This transformation is denoted "Surface" in Figure 3.2.

Decoration Transformation

The fourth dimension refers to a transformation, T_D, of the surface of the pottery to a decorated surface, whether through decorative modification of the surface or application of a design to the surface. Decoration has two separate modalities depending on whether the decoration is done on wet clay or added to the surface of dry clay (Brown 1976: 129), as indicated by the solid arrows and dashed arrows in Figure 3.2.

The decoration transformation is the most complex of these four transformations in that underlying the transformation is the conceptual system through which a design is produced. The decoration transformation is not strictly part of a production sequence for making a pot and so decoration can be distinguished from the functional utility of the pottery object (Rye 1981: 3). A finished pot must have physical properties, form, and a surface, but decoration is not required for it physically to be a pottery object—though decoration may be necessary for the pottery object to be considered as an instance of a conceptual system that includes design as a component.

The physical properties, form, and surface transformation(s) reflect the conceptualizations that are part of a production sequence that links properties at the phenomenological level with the conceptual patterning (in a particular cultural context) that makes for a particular kind of pottery object (e.g., bowls or jars), as opposed to simply a unique pottery object that only shares statistical patterning with other pottery objects. The decoration transformation can be null for any pottery object; hence, when a particular design is applied to a pottery object, the artisan is imposing a property on the pottery object rather than the property arising through the production of the pottery object.

While the geometric form of the pottery object may influence the execution of the design on the pottery object, the design itself has to be understood by reference to a conceptual system underlying how a design is produced, such as hierarchical (e.g., Jernigan 1986, but see critique by Douglass and Lindauer 1988) versus nonhierarchical designs. In addition, designs may crosscut other conceptual systems involved in pottery production such as wares. The Pinedale style in southwestern pottery, for example, characterized by "symmetrical designs with opposed or interlocking solid and hatched motifs with two to four repetitions of the basic motifs (Carlson 1970; Graves 1984: 4)," is also "the most widespread decorative style employed in Southwestern prehistory" (Crown 1996: 241–242). The Pinedale style was used for decoration with four different southwestern wares—Hopi Yellow Ware, Cibola White Ware, Zuni Glaze Ware, and Rio Grande Glaze Ware (Carlson 1982). Even more broadly, the conceptual system for design need not be specific to pottery and the same design principles may be used for a variety of decorated materials, as Hays-Gilpin (1996) has argued for some Anasazi basketry, pottery, and textile decorations. For the Prayer Rock District of the San Juan Basin, Hays-Gilpin argues that basketry, pottery, and textiles utilized the same basic design (in contrast with art on rock walls and boulders, which used a different set of design principles)—in contradistinction with previous

authors (e.g., Morris 1927: 194–197; Roberts 1929: 119; Amsden 1949: 122), who viewed Basketmaker pottery designs simply as copies from designs used for baskets.

These examples illustrate the extent to which pottery decoration can be viewed as the intersection of two conceptual systems—one relating to the production of pottery objects and the other to the production of decorative designs. The design conceptual system may be based on concepts that do not directly relate to pottery production, thus making the decoration an ancillary aspect of the pottery that enables decorated pottery to simultaneously have both utilitarian and cultural/symbolic functions. The widespread use of the Pinedale style over a variety of wares, each of which has its own—and only partially overlapping—spatial distribution in the Southwest (Crown 1996: Figure 26.1), raises the question of why a single decorative style should be so widespread and why it spread so widely over a very short time period from its introduction around 1280 AD (Crown 1981, 1994), since its geographical boundaries are far greater than would be expected on the basis of societal boundaries that existed in the Southwest prior to the spread of the Pinedale style.

The origin and subsequent spread of the style appears to have occurred in conjunction with population movement from the Tusayan-Kayenta area into east-central Arizona (Carlson 1970) and was part of the blurring of prior societal boundaries expressed through the spread of a regional cult that may have been a precursor to the Ketsina Cult (Adams 1991), as shown by the use of iconic design elements in the Pinedale style (Crown 1990, 1996: Figure 26.2). In brief, the origin and spread of the Pinedale style provides a clear illustration of how pottery provides a medium for the intersection of different conceptual systems, thereby making decoration far more complex than just being one other aspect of a pottery object. From the perspective of classification, it makes evident the problem with trying to formulate a single pottery classification system. Any single classification system would either downplay the similarity of the Pinedale style of decoration if it is based on ware differences, or would downplay the differences in wares if the classification system focuses on similarity based on the Pinedale decorative style.

Transformation Summary

The four transformations are independent in that, for example, the characteristics of the clay place only a small constraint on the shape that can be made using that clay. The surface obtained through the method used to produce the shape of the pottery object can be modified through scraping and smoothing techniques to arrive at a surface that bears little or no resemblance to the surface resulting from producing the shape of the pottery object (though in some cases, such as corrugated pottery, the initial surface was only partially modified and some of the initial features of the surface are incorporated in the design for the surface of the finished pot). Finally, the choice of the decorative design that will be applied to the pot (if any) is mainly constrained (if at all) by the overall geometry of the pot as it relates to the overall geometry of the design, whereas the content of the design is free to vary within these geometrical constraints.

The concept of a ware involves both the first and third transformations. The slip and its color constitute a means to transform the surface and is not a property of the paste, per se, but figures prominently in the kinds of ware that have been distinguished. The "red" in southwestern red wares, for example, refers to the color of the slip used to make the surface of the pottery object. For some wares, there is a strong correlation between the characteristics of the paste and the properties introduced through the third and fourth transformations. For example, Anasazi gray wares are "unpainted, unslipped, and generally unpolished" (Wilson and Blinman 1995: 65).

Space and Time Systematics

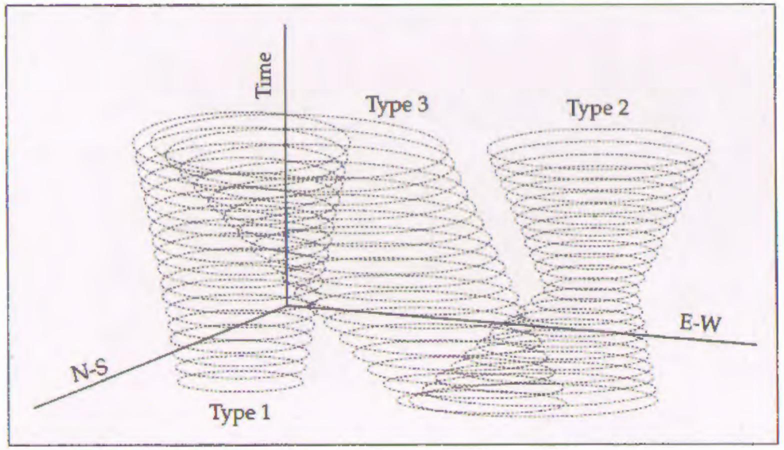
Because space and time bring together three central aspects of how we understand human social systems, space/time systematics is a fundamental aspect of archaeological research. First, the spatial component by itself provides us with the spatial scale for a particular society and identifies—through its geographical location—the range of resources that were available nearby for exploitation by members of that society. Second, the spatial component in conjunction with the population size of the group (e.g., estimated from the density of artifact material at the same time period) provides us with the population density, which reflects the intensity of resource exploitation; the latter relates to aspects of social organization that may have arisen as a way to provide the organization of labor required for that level of resource exploitation. Finally, the time dimension provides the basis for considering evolutionary changes at the behavioral, social, and cultural levels. Thus, space/time systematics are fundamental for addressing questions that relate to adaptation, organization, and change—three central aspects for understanding the time trajectory of any social group.

Some writers on archaeological classification have viewed space and time as almost inseparable components of what constitutes a type even though there have been two conceptual usages of these terms and a

third, methodological use. The first usage links an artifact to a type for which it is an instance and the type as a cultural construct to the cultural domain in which the type is conceptually embedded. This gives rise to the historical method of locating an artifact in a space/time grid for the purpose of working out the spatial and time dimensions of artifact types taken to be instances of cultural constructs.

Rouse made the procedure explicit by distinguishing between the spatial boundary for a culturally salient type at a single point in time and time-dependent change in that spatial boundary, based on sites within a single, culturally homogeneous region. For the former, he drew upon the ethnographic work of Spier (1928), who considered the spatial distribution of cultural traits both within and between tribes—all of whom were essentially contemporaneous. Rouse was mindful of the need to consider the spatial distribution of cultural traits for a single point in time so as to not confound spatial and temporal sources of variation in the space/time systematics of the distribution of cultural traits. For the latter, he drew upon the work of Olson (1930) that considered time changes in cultural traits within Chumash society—that is, changes through time within a (presumably) culturally homogeneous group. The argument, with both space and time taken into consideration simultaneously, can be graphed as shown in Figure 3.3.

Figure 3.3: Hypothetical simultaneous space and time trajectories for three pottery types



While space/time systematics in this conceptual/historical sense links artifact types to space and time dimensions, some researchers have used space and time in a different way with goal determining whether or not

the patterning found in a group of artifacts constitutes the outcome or instantiation of shared cultural concepts. Consider the difference between a type, call it T, and a variety, call it V, and how both are distributed in space and time. The type, T, is part of the cultural repertoire of a group of individuals and should have a more extensive spatial spread with greater coherency through time than would be true for a variety, V, since the variety expresses aspects of the artifact that arose through the idiosyncrasies of the artisan or those attributes of the artifact that are not part of the pattern of modes that constitute the type. The type/variety distinction implies that the space/time pattern for a group of artifacts becomes a "signature" of whether the group of artifacts is representative of a type or a variety. Both the type and variety share the property of displaying patterning among the attributes distinguished on the artifact; hence, the type/variety distinction cannot be determined from the properties of the artifacts alone. Rather, the distinction arises from the expected differences in their space and time distribution. This implies that one does not first determine types and then work out their space/time systematics. Instead, from this perspective, space/time systematics and the delineation of types (and varieties) are not separable but need to be viewed interactively.[7]

Yet a third, methodological usage of space and time dimensions arose when space and time systematics were proposed as a way to validate the intuitive types formulated by the archaeologist. Krieger's comment that "the dividing lines between a series of types must be based upon *demonstrable historical factors*, not . . . upon the inclinations of the analyst or the niceties of descriptive orderliness" (p. 272, emphasis added) implies that purported types should be validated by demonstrating that they have coherent space/time distributions. The reference to "historical factors" links the type of the archaeologist to the "'culture trait' of ethnography" (p. 272) and thereby to the task of "retracing of cultural developments and interactions" (p. 272). Types, in this sense, are not determined solely by consideration of the properties and features of artifact material considered in isolation, but depend on the space/time distribution of the purported types: "Those details which do consistently combine through site after site, in the same temporal horizon and in the same culture complex, may thus be safely regrouped into *tentative types*" (p. 280). In effect, Krieger was arguing that if a type were purely a construction on the part of the analyst and without cultural relevance, then the distribution of the purported type in space and time need not be patterned in a manner consistent with cultural spatial and temporal boundaries; hence, the type should be rejected. The means for conducting this test required comparison across sites to see if the purported pattern showed spatial

and temporal patterning indicative of the type having cultural saliency. This meant, according to Krieger, that one could only determine culturally relevant patterning through comparison between sites, a claim challenged by Albert Spaulding with the introduction of statistical methods for delineating types—the topic of the next chapter.

4

From Intuitive to Objective Classifications

The use of space/time systematics as a means to validate "tentative types" came under attack by Albert Spaulding as part of his general concern with developing rigorous and objective methods to give archaeology a secure analytical foundation. Spaulding challenged Krieger's historical/site comparison method for identifying types in his influential paper "Statistical Techniques for the Recovery of Artifact Types" (1953).

Spaulding viewed Krieger's site comparison method as deficient since it lacked an adequate *analytic* methodology for ensuring that the purported patterning of attributes was valid and not happenstance or due to the vagaries of the researcher. Whereas Krieger's method assumed that whatever claims about types might be advanced from the study of a single site needed validation using between-site comparison, Spaulding argued that "the presence of an adequate method for investigating consistency and range of variation *within the site* obviates a comparative study so far as the questions of the existence and definitive characteristics of a type are concerned" (1953: 305, emphasis added). From this it followed that "*historical relevance . . . is essentially derived from the typological analysis*; a properly established type is the result of sound inferences concerning the customary behavior of the makers of the artifacts and cannot fail to have historical meaning" (1953: 305, underlining added).

With that comment, Spaulding claimed to introduce what had been lacking in typological studies—an objective, analytic method for discovering and validating hypothesized patterning in artifact material. Patterning of artifact characteristics is central to any notion about a type and the fundamental methodological task is both to discern consistent patterning among artifacts and validate claims of patterning. Adams and Adams' (1991) reversion to intuitive sorting based on a gestalt approach highlights clearly what Spaulding was challenging through his goal of replacing an intuitive approach to type identification with a rigorous, objective analytic method. For this task, Spaulding turned to statistics

as a way to extend archaeological reasoning about the nature of types (1953: 313) and introduced the idea that a type should be based on patterned combinations of attributes determined from statistical analysis of artifact material. Though the focus was on statistical methods, equally important was his concern that statistical methods be used as a way to extend archaeological reasoning. Spaulding was not redefining what constituted a type; rather, his goal was to give the intuitive notion a secure, methodological foundation that satisfied the canons of scientific inquiry. The shift to statistical methods for so doing in the manner introduced by Spaulding, however, is problematic.

Attribute Combinations

Spaulding's underlying justification for focusing on the combinations of attributes as the definition of a type stemmed from his assertion that the formation of types is "a process of discovery of those attribute combinations favored by the makers of the artifacts" (1953: 305). The phrase "attribute combinations" as the defining characteristic for a type is ambiguous and can be read in two ways. One is that the type is determined by the attribute combinations observed on an artifact, such as "jar, red clay, smooth surface"; the other is that the combination must have occurred more often over some population of artifacts than would be expected by chance alone. The first implies that the pattern of attributes defining a type can be observed on a single artifact without statistical analysis, whereas the second reading implies that patterning is identified through statistical analysis aimed at finding patterning expressed in the aggregate, but not on individual cases. One cannot observe a single pot and determine if a combination of attributes on the pot could be due to chance without simultaneously taking into consideration the attribute combinations that occur on other pots. The first interpretation views a type as having a qualitative definition; the second asserts that a type is defined quantitatively.

Spaulding used attribute combination in the second sense and wanted to know if certain combinations occur more frequently than would be expected by chance alone; that is, he wanted to know if the inclusion of one attribute on an artifact was independent of the inclusion of a different attribute on the same artifact due to decisions made by the artisan. Because he was asking about the pattern observed in the aggregate, Spaulding was led to implement the "pattern in the aggregate" definition of a type by using statistical methods for discerning patterned combinations of attributes over some population of artifacts. Patterning would be found in the frequency with which particular attribute combinations occurred, he argued, and this led to the use of statistical methods since these methods deal with discerning patterning in aggregated data. In addition,

statistical methods could be applied to a sample of artifacts from the same site and thus the conclusions reached from the analysis did not require the between-site comparison advocated by Krieger. It appeared that a method for the discovery of types could be reduced to applying statistical methods to the frequency with which attribute combinations occurred on artifacts from the same site.

Unfortunately, Spaulding's argument involved several errors, one of which was an invalid shift from the *combination* of attributes observed on individual artifacts as the basis for defining a type to defining a type on the basis of the *frequency* with which these attribute combinations occurred over a population of artifacts. His argument is additionally flawed by an unjustified conceptual shift regarding what constitutes an artifact type from combinations of modes to combinations of attributes and then using the term "attribute" inconsistently. We will briefly consider the latter flaws in his argument and then examine in more detail the central problem: incorrectly using frequency counts of attribute combinations to define artifact types.

Mode Combinations versus Attribute Combinations

Though the argument appears to be just about methods, Spaulding was dismissing the attribute $\rightarrow$ mode$_1$ $\rightarrow$ mode$_2$ distinction with its associated claim that types are defined by mode$_1$ or mode$_2$ patterning. Spaulding defined types on the basis of attribute combinations without taking into consideration whether the attributes in question had cultural relevance. Spaulding's underlying argument was that if a certain attribute combination occurs more often than would be expected by chance alone, that attribute combination must have arisen through choices and decisions made by the artisans.

Idiosyncratic attribute combinations due to a particular artisan or group of artisans are thus treated co-equally with attribute combinations that supposedly have cultural relevance. As a consequence, the type/variety distinction loses its utility since any statistically significant combination of attributes is part of what constitutes a type. The only question is whether certain attribute combinations appear to occur in a nonrandom manner and a type became synonymous with "nonrandom clustering of their observable attributes" (Redman 1978: 162).

Spaulding's argument depended upon a definition of a type that is partially at variance with the idea of a type as representing a cultural concept. While there does not appear to be any disagreement that artifacts that are instances of a type will display patterning in at least some attributes or attribute combinations, the type = cultural construct also allows for some of the attributes or attribute combinations to be ignored when

considering patterning relevant to type definitions. Thus, while we may form the implication artifact type ⇒ patterned attribute combinations for *some* set of attributes, the converse argument need not be valid for *all* sets of attributes since attribute combinations can be produced for reasons unrelated to cultural saliency. Spaulding's argument requires complete correspondence between a type and its definition and attribute patterns found over instances of that type, whereas a type viewed as a cultural concept does not require isomorphism between a type definition and a design for producing an artifact that is an instance of the type. In contrast, in Spaulding's framework, there are no varieties—only types.

Inconsistent Use of Attribute

Spaulding was inconsistent in his usage of the term "attribute." Spaulding first used "attribute" to refer to a trait or characteristic of an artifact, but when he turned to statistical methods, the term takes on the meaning of a variable when he implicitly and erroneously equated association of variables with identification of nonrandom combinations of variable values. The inconsistency surfaced when he shifted from "combination of attributes" (1953: 305) to "association of attributes" (1953: 306) as the defining characteristic of a type. In the first usage, the term "attribute" has the meaning of a characteristic or trait that can be observed on an object. Thus, the surface of a pot might have the attribute "smooth" or the attribute "stamped" and the clay temper might have the attribute "grit temper" or the attribute "shell temper." Under this definition of an attribute, a type defined as a combination of attributes would be something like "smooth surface with shell temper." Here Spaulding was consistent with the terminology introduced by Rouse and other researchers.

When Spaulding turned to statistical methods to determine whether there is a nonrandom combination of attributes, his use of the term "attribute" changed its meaning. Spaulding now used a statistical measure of the association between a pair of variables to compute what he referred to as the association of attributes. Hence by association of attributes he was referring to an association between variables, not to combinations of attributes. The term "attribute" no longer refers to a feature of an artifact but to a variable whose values are the particular features of the artifacts.

From a statistical viewpoint, association of variables has to do with whether two variables are independent of one another, not whether a value from one variable has been combined in a nonrandom, patterned way with the value of the other variable. Further, even if the variables are independent, one cannot automatically infer that all the variable value combinations are without pattern. The reverse is valid, but only in a limited sense. Association of variables does inform us that the frequency with

which *some* combination of variable values occurs must be nonrandom and hence patterned, but it does not inform us, for example, about what combination of variable values were occurring more frequently than would be expected by chance—for example, favored by the artisan.

Attribute Association versus Attribute Combination

The central issue of concern with Spaulding's argument runs much deeper than possible inconsistencies in the use of the term "attribute" and reflects a deep, and pervasive, difficulty that arises with attempts to provide an objective means for identifying artifact types. The difficulty has to do with lack of concordance between the underlying processes responsible for the patterning in data and the properties of the statistical methods applied to the data brought forward for analysis. The attribute/variable association used by Spaulding, for example, does not measure the topic of interest (patterning in combinations of attributes/values). To see this, we need to consider several examples modified from Spaulding's examples.

Consider Table 4.1 (modified from Spaulding 1953: Table 7, p. 306). Spaulding computed the quantity $A = [(a+d)-(b+c)]/(a+b+c+d) = 0$ for this table. He asserted that this is "the coefficient of association for the attributes grit temper and cord wrapped paddle stamped surface " (p. 306); hence, Spaulding viewed A as a measure of the extent to which a particular attribute combination is nonrandom. He then contrasted the pattern of attribute combination frequencies in Table 4.1 with those in Table 4.2 (modified from Spaulding 1953: Table 8) and computed $A = 1.0$. Spaulding noted that the pattern of frequencies in the two tables matches the intuitive notion of an artisan being indifferent to attribute combinations (Table 4.1) or an artisan favoring certain attribute combinations (Table 4.2).

match with the intuitive notion of artisan.

Table 4.1: Temper versus Surface Treatment (1)

		Variable: Surface Treatment		
Variable	Attributes	Grit	Shell	Total
Surface Treatment	Paddle Stamped	a=25	b=25	50
	Smooth	c=25	d=25	50
	Total	50	50	100

Table 4.2: Temper versus Surface Treatment (2)

		Variable: Surface Treatment		
Variable	Attributes	Grit	Shell	Total
Surface Treatment	Paddle Stamped	a=50	b= 0	50
	Smooth	c= 0	d=50	50
	Total	50	50	100

Though the value of $A = 0$ for Table 4.1 and $A = 1$ for Table 4.2 matches the interpretation of the patterns displayed in these two tables, the correspondence is due only to the particular values that Spaulding used for the two tables. Consider Table 4.3, where it appears that the attribute combination Paddle Stamped + Grit Temper is favored. The value of A for this table is also 0: $A = [(45 + 5) - (25 + 25)]/100 = 0$.

Table 4.3: Temper versus Surface Treatment (3)

		Variable: Surface Treatment		
Variable	Attributes	Grit	Shell	Total
Surface	Paddle Stamped	a=45	b=25	70
Treatment	Smooth	c=25	d= 5	30
	Total	50	50	100

Spaulding incorrectly treated a measure of association, A, between variables as if it measures the extent to which a particular combination of attributes was favored by the artisan. The value of A, however, only reflects the degree of concordance between the total number of observations in one diagonal (e.g., $a + d$) and the total number of observations in the other diagonal (e.g., $b + d$), not the extent to which a particular attribute combination is favored.

Spaulding then used a measure for a contingency table (known as a chi-square statistic) purportedly to assess whether patterning in attribute combinations is simply due to the vagaries of sampling from a population. The chi-square statistic is based on the statistical notion of variable independence. Two variables are said to be independent if the probability that one variable takes on a specified value (such as Shell for the variable, Grit Temper) for the entities in a population is the same regardless of whether one knows the value of a second variable (such as Surface Finish) for each entity. The concept of statistical independence approximates the archaeological notion of combinations of attributes favored by the artisan. With nonindependent dimensions, the decision made by the artisan for one dimension (such as choice of temper) affects the choice made by the artisan on another dimension (such as choice of surface finish)

Though the concept of statistical independence relates to the notion of attribute combinations favored by the artisan, it is not equivalent to the latter. Consider Table 4.4. Here it appears that the combination Smooth Surface + Grit Temper is preferred since c = 70 for this combination. But for this table, chi-square = 0; the two variables are independent since one-eighth of the pots have a Paddle Stamped surface regardless of whether the temper is Grit or Shell.

Table 4.4: Temper versus Surface Treatment (4)

		Variable: Surface Treatment		
Variable	Attributes	Grit	Shell	Total
Surface	Paddle Stamped	A=10	b= 2	12
Treatment	Smooth	C=70	d=14	84
	Total	80	16	96

Paradigmatic versus Taxonomic Classifications

Spaulding also assumed that the order in which variables are considered is not relevant; hence, a typology has the form of a paradigmatic classification. The analytic importance of the difference between a paradigmatic classification and a taxonomy became evident with Robert Whallon's (1972) attempt to reconstruct an intuitive pottery typology—the Owasco pottery typology developed by Ritchie and MacNeish (1949)—using the methods advocated by Spaulding. The typology had been constructed using patterns of attribute combinations shown to have spatial and temporal significance. Implicit in the typology was a taxonomic structure: not all attributes were considered to be of equal importance for all pottery, and different criteria were used to define the pottery types.

Whallon was not able to re-create the typology using the method advocated by Spaulding and commented, "It is clear that the standard Owasco typology cannot be supported statistically by the very method proposed to create it and similar typologies" because "the actual procedure of type definition and the logical structure of the typology itself are quite incongruent with the stated concept of what a type should be and what it is believed to be" (1972: 15). Whallon observed that no simple modification of Spaulding's method, such as Sackett's (1966) attempt to form a typology of Aurignacian end-scrapers using contingency tables, would suffice since the problem was due to the discordance between a statistical method based on a paradigmatic structure and the taxonomic tree structure used to represent the Owasco pottery typology. Whallon further noted that the numerical taxonomic procedures advocated by Sokal and Sneath (1963) in a biological context would also fail due to their simultaneous use of all variables when constructing a measure of similarity between objects.

Whallon's solution to the problem of assuming a paradigmatic structure recognized the underlying discordance between concept and method, but kept the assumption that a measure of association based on frequency counts provides the basic information on the patterning of attribute combinations. Whallon constructed a typology in the form of a

taxonomic structure by using a method of association analysis (Williams and Lambert 1959, 1960) that treats each attribute as either present or absent, and then searches for the attribute that has the strongest pattern of association over all other attributes not logically inconsistent with the attribute in question. The collection is then divided into two parts: (1) artifacts with the attribute in question and (2) all other artifacts. The procedure is then applied recursively to these two subgroups. The recursion is continued until a criterion for stopping (such as a nonsignificant chi-square value) is reached.

This procedure allows for different criteria (i.e., attributes) to be the basis for subdividing a group of objects. Whallon was able to construct "objective" tree diagrams that reasonably matched Ritchie and MacNeish's typology for the Owasco pottery, though the degree of match depended on the criteria employed for selecting an attribute to be used for group division and/or stopping the division process. The ambiguity arises due to reliance on measures of association based on frequency counts that reflect the *usage* of artifact types rather than the *choices* made about attribute combinations by the artisans.

Variable Association versus Patterns of Attribute Combination

The underlying problem being discussed here has to do with discordance between a statistical framework concerned with *patterns of association among variables* and an archaeological framework concerned with *patterns of attribute combinations*. Spaulding treated the two frameworks as if they are synonymous for the purpose of constructing a supposedly objective way of measuring whether the artisans favored certain attribute combinations when he focused on measures of (attribute = variable) association. Therein lies his fundamental error in assuming that a type defined on the basis of the pattern of attribute combinations could be measured through the frequency with which the attribute combinations occurred in a data set brought forward for analysis.

We can illustrate the problem more precisely with a hypothetical example. Suppose that a village is made up of four clans, each with its own residence area in the village and its own characteristic way of making pottery that can be described using two pairs of two attributes: the *A* and *a* attributes and the *B* and *b* attributes. Suppose Clan 1 always uses the *AB* combination when making pottery, Clan 2 the *Ab* combination, Clan 3 the *aB* combination, and Clan 4 the *ab* combination, and each clan makes and uses the same amount of pottery in its residence area (see Table 4.5). Suppose in addition that breakage rates of pottery are the same

Table 4.5: Pottery Made by 4 Clans (Hypothetical Data)

Attributes	B	b	Total
A	25	25	50
a	25	25	50
Total	50	50	100

for all four clans. Further, all four clans dispose of the broken pottery in a common garbage area, which has been excavated by an archaeologist. Assume the archaeologist considers the garbage area to be representative of the population of all pottery from the site. Since all combinations occur equally frequently in this population, he or she concludes—using Spaulding's argument that the frequencies with which attribute combinations occur are the defining characteristic of a type—that no type of pottery can be distinguished since all attribute combinations are equally frequent. Yet this is patently false since each clan has its own favored combination of attributes.

To make matters worse, suppose further excavation recovers unbroken pottery objects in situ from each of the four quadrants of the village that made up the residence areas for the clans. If a population is now defined as the pottery from a single quadrant, then in each of the four possible populations, only one attribute combination occurs (see Table 4.6 for Clan 1); hence, each pottery population now contains a single type. Thus—in contrast to the conclusion based on the sherds—we conclude that for the unbroken objects, there are four types of pottery, each with its distinctive spatial distribution in the site.

Table 4.6: Pottery from a Single Clan

Attributes	B	b	Total
A	25	0	25
a	0	0	0
Total	25	0	25

Both interpretations about types cannot be correct since no changes are posited in the production of pottery by artisans, only differences in the *usage* of the pottery that has been produced. Pottery types have not changed; only the activities and frequency of activities for which the pottery types are involved. The frequency counts are not measuring the nonrandomness of attribute combinations but the frequency with which these attribute combinations occur in activities that involve these artifact types. For the data in Table 4.5, the activity of discarding broken pottery is indifferent to pottery types and so we obtain similar frequencies for each of the possible attribute combinations. In contrast, Table 4.6 shows

the relative frequency with which Clan 1 makes each of the four possible attribute combinations. These frequencies measure the usage of a type in an activity or series of activities by a single clan, and the frequencies reflect artifact types only to the extent that activities and the frequency with which activities occur are based on artifact types. More generally, attribute combinations determine the types and the frequencies represent both the degree of association of an artifact type with an activity and the frequency with which that activity is performed. Consequently, types need not be distinguishable on the basis of frequency counts.

The nonrandomness of attribute combinations relevant to type definitions arises from those combinations being part of cultural concepts underlying the production of artifacts. The patterning of attribute combinations is just that: attribute combinations that are deemed to "go together." From this perspective, attribute patterning can be displayed in an incidence matrix whose entries are 0 when an attribute combination does not occur or 1 when an attribute combination occurs (see Table 4.7).

Table 4.7: Incidence Matrix for Table 4.5

Attributes	B	b
A	1	1
a	1	1

The incidence matrix cannot be taken literally as the definition of a type or types since it may contain attribute combinations that do not have cultural saliency. The mapping from concept to artifact via the production procedure used by the artisan does not require that only attribute combinations with cultural saliency be used by the artisan. For the information content embedded in the incidence matrix to represent types, the incidence matrix must be based on attribute combinations that are culturally salient and thus shared across a cultural community. Some attribute combinations formulated solely at the time of artifact production can be specific to an artisan and part of the definition of a variety.

To the extent that the cultural aspect of an artifact does not encompass all attributes of the artifact, a criterion other than the incidence matrix must be invoked to determine what attribute combinations have cultural saliency. To see the difficulty, suppose we have another context in which the attribute combinations do not map onto social units but instead each potter produces pottery using all four attribute combinations. Assume potters are indifferent to attribute combinations and users are equally indifferent to attribute combinations, so that each attribute combination has equal likelihood of being produced and used. Under these conditions, we would again have data with relative frequencies that match Table 4.5.

Any measure of statistical association based on Table 4.5 would treat the two contexts exactly the same way even though there is a striking difference between the two contexts with respect to both the production and spatial distribution of attribute combinations.

In the example of a village with four clans, attribute combinations for unbroken pots have a strong spatial association matching the spatial location of the clans producing each type of pottery. In the example of potters indifferent to attribute combinations, the spatial distribution for each attribute combination is the same for each attribute combination. Thus, whether an attribute combination constitutes a type (in the sense of an attribute combination preferred by the artisans and users of the pottery) can only be confirmed (or disconfirmed) in this example by considering the spatial distribution of the attribute combinations. The insistence of Rouse, Krieger, and others that types should be based on attribute combinations that also have spatial and temporal significance identifies an indirect method for discerning the attribute combinations that should be part of a type definition. Their arguments reflect the presumption that artifacts produced in accordance with cultural concepts will have a spatial pattern reflecting the spatial parameters for the manufacture and use of artifacts made in accordance with cultural concepts.

Spaulding correctly noted that if we have a means to determine types that are culturally salient, they would have spatial and temporal significance under the assumption that cultural concepts have spatial and temporal dimensions in their occurrence. But like Rouse, who proposed a conceptual basis for determining cultural saliency through his distinction between an attribute and a mode but lacked an analytical method for implementing the attribute/mode distinction, Spaulding did not provide a valid means for identifying attribute combinations that have cultural saliency. His reliance on statistical measures of association confounded patterning at the behavioral level with patterning at the conceptual level. We will take up this topic more extensively in Chapter 5.

Let us assume that the four types, one made by each clan, are all culturally salient. Although the frequency counts do not directly provide us with information on the attribute combinations that are conceptualized by the artisans as going together, they are nonetheless informative about how the artifact types are related to patterns of behavior and thereby introduce another dimension relevant to the organizational pattern introduced through behaviors associated with the types.

Artifact Frequencies, Behavior, and Usage Types

Artifact frequencies relate to the spatial and temporal location of artifacts since frequencies are measured over a population of artifacts and

populations of artifacts are usually delineated in terms of spatial and temporal location. From the viewpoint of the artisans and users of artifacts, the spatial and temporal locations of artifacts arise from the activities in which the artifacts were embedded. We can relate these differences among the artifacts to differences in how they were embedded in activities.

For example, consider again the process of pottery use and discard in the village with four clans; the process begins with manufacture, continues with usage and breakage, and ends with disposal in a common garbage area. For this behavioral sequence, there is but one kind of pottery since the differences that can be distinguished at the level of pottery manufactured by clans have no bearing on the patterning produced through disposal of broken pottery. Disposal of pottery does not distinguish pottery types since (in this example) disposal takes place in the same manner regardless of how the pottery was manufactured. Thus, we conclude that there was a single pottery type from a usage viewpoint based on the pottery in the garbage area. Hence, we would say that the behavior sequence of pottery manufacture, use, and discard results in a single Usage Type = $\{AB, Ab, aB, ab\}$ with relative frequency distribution as shown in Table 4.5. In contrast, pottery manufactured in accordance with clan-specific production of pottery (see Table 4.6) will have type specific frequency distributions that reflect differences in pottery production frequencies among the clans.

Both a population based on the garbage area and the four populations each based on clan-specific pottery manufacture are valid analytical constructs since each represents the consequences of behavior patterns that have produced the patterning (or lack of patterning) in the population of artifacts that has been identified. Consequently, selecting a population as the aggregate to be used to identify patterning imposed over the pottery types depends on which structuring process involved in the formation of a population is relevant. The latter is not a statistical question. For the goal of determining the pottery types that occur in this site, the clan-specific process by which the pottery was manufactured is more relevant. For this process, the pottery in the garbage area is a heterogeneous population made up of four types of pottery, each manufactured according to a clan-specific manufacturing processes. Any attempt to elucidate pottery types from this heterogeneous population requires methods that enable us to partition the data set brought forward for analysis into its constituent, homogeneous subsets, each containing one type of artifact. Methods for so doing will be discussed in Chapter 8. Here it suffices to note that methods based on analyzing patterns among the frequency counts for

the artifact types do not determine the set of artifact types that should be grouped together based on how the artifact types were incorporated into activities.

We can illustrate the argument with two actual examples. The first is based on Lewis Binford's (1977) analysis of artifact types that were part of hunting trips made by a group of Nunamiut hunters. The second involves reanalysis of the classification of pottery types identified as part of the Cibola Archeological Research Project conducted in the El Morro Valley in New Mexico by Patty Jo Watson, Steven LeBlanc, and Charles Redman (Redman 1978).

Nunamiut Usage Types

For the Nunamiut data, what constitutes types is not problematic; rather, the question being addressed had to do with the basis for the patterning imposed over artifact types (see Table 4.8) through the conduct of activities. According to formal properties of the artifacts, one might be tempted to gloss the first column of Table 4.8 as "things—tools," the second as "food," and the third as "clothing." These are the headings used by Binford (1977: Table 5) for the data presented in Table 4.8. But that categorization is violated by the inclusion of a cup and a coffee can in the second column and a big knife and an extra line in the third.

Table 4.8: Three Categories of "Basic Trip" Gear

Category 1: "Items needed for goal of trip"	Category 2: "Items needed to quench hunger"	Category 3: "Items needed for protection in case of mishaps"
Dog team or ski-doo	Pilot bread*	Mukluks*
Axe*	Coffee*	Extra line*
Sled skin*	Sugar*	Socks*
Matches*	Cup*	Extra skin*
Rifle*	Coffee can*	Big knife*
Ammunition*	Corn meal*	Parka*
Snow probe*		
Skinning knife*		
Field glasses		

Modified from Binford 1977: Table 5.

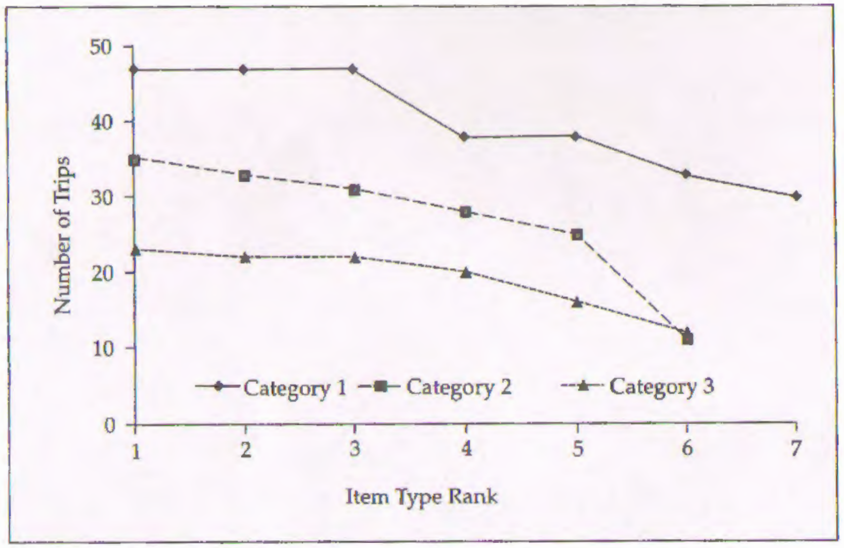
* Items listed in rank order within a category, based on number of trips for which the item was included.

When asked about the grouping of artifacts, the Nunamiut gave rationales that relate to contingency planning for a trip indicated by the headings in quotes for each column in Table 4.8 and not to the formal

properties of the types (Binford 1977). Variation in the actual number of artifact types taken on a trip related to the length of the anticipated trip, the type of trip, and the way some items may be stored or cached. Binford concluded that analysis of the variation in the frequency of artifact types "would rather faithfully reflect the concrete dynamics of *the hunters' behavior* in the field . . . [and] archaeological remains refer directly to the organization of behaviour itself, and not the cognitive conventions in terms of which behaviour may be expressed or anticipated" (pp. 33, 36, emphasis added). In other words, the categorizations made by the Nunamiut for the artifacts in Table 4.8 cannot be determined from frequency counts of the artifacts summarized over all trips since the frequency counts would reflect the frequency with which trips of different lengths took place and differences in the kinds of artifacts taken on a trip. The latter is determined by three components of a trip: (1) items needed to carry out the trip; (2) items needed to deal with hunger; and (3) items needed to deal with possible mishaps. The relationship between the artifacts in each column and the category represented by that column is determined by the importance of an artifact for that task, and not simply by formal similarity of artifacts in each column.

The three categories are usage types formed from artifact types since an entry in a column is an artifact type. The number of times each tool type was taken on one of the 47 trips is shown in Figure 4.1, with tool types grouped by category (= usage type). Each category has a distinct pattern; hence, the usage types appear to be the primary criterion for decision making about tool types for a trip. This conclusion receives support from data on usage type and length of trip. When trip lengths are divided by breaks in the data into long (> 150 km), medium (> 30 km), and short (< 30 km) trips, all three categories of tool types are taken on long trips; Categories 1 and 2 are almost always taken on medium trips and Category 1 tools are taken about one-half the time; and for short trips, Category 1 is taken most often, then Category 2 and finally Category 3. Hence, differences in the frequencies for the artifact types correlates with the requirements imposed by the length of the trip and the categorization of the tools into usage types.

Figure 4.1: Patterns for Nunamiut trip usage of item types. Item type categories are shown in Table 4.8. Rank of item type within a category is based on Table 4.8



Cibola Pottery Usage Types

The second example deals with the classification of pottery artifacts from the Cibola Archeological Research Project conducted in the El Morro Valley in New Mexico by Patty Jo Watson, Steven LeBlanc , and Charles Redman (Redman 1978). Three pottery forms—bowl, jar and ladle—and three, color attributes for the clay—red, yellow-red and white—were identified. The dimensions of form and color form the two-way paradigmatic classification shown in Table 4.9.

Based on Spaulding's definition of a type as a nonrandom association of attributes, the color attribute with the highest value for each form was identified as a type (data in bold, Table 4.9); for example, Redman concluded that the bowls with yellow-red clay form a type. This leaves unclear the status of the red and the white bowls. If they are not types, then what are they? Their frequency implies they are not idiosyncratic objects. That red bowls should also be considered as a type is suggested by Redman's (1978: 180) observation that most of the red ware is in the form of bowls. Similarly, we should consider white jars to be a type since they are the most frequent kind of jar; yet yellow-red jars are almost as frequent a kind of jar. Hence yellow-red jars should also be a type. Indeed, there is no reason not to consider each of the cells in Table 4.9

Table 4.9: Pottery Form versus Color of Clay

	Color		
Form	Red	Yellow-Red	White
Bowl	167	**1601**	136
Jar	73	344	**351**
Ladle	3	11	**15**

Modified from Redman 1978: Table 8.

as representing a type. Hence, we conclude from these data that there are nine pottery types represented by the nine cells in Table 4.9. This, however, does not take into account the frequency with which each of these nine types occurs in the data set.

The frequency counts are not measuring the propensity of the artisan to make certain combinations of attributes but the frequency with which each of these nine types was used in some activity at the time of site occupation. The potters did not make a large number of bowls with yellow-red pottery because the bowl + yellow-red pottery was a favored attribute combination, but because that combination of attributes made for a bowl type that apparently was used frequently in the site. Had that combination been less favored, it would still be a type of pottery the potters made. The frequency counts represent the pattern for the *usage* of pottery types, including whether two or more pottery types are used with a similar frequency. Similar frequencies imply that not all of the distinctions making up the paradigmatic classification are equally recognized at the level of activities involving these pottery types.

We can use the frequencies to define several usage types. The red and white bowls statistically occur with the same frequency at the 5% level of significance ($X^2 = 3.17$, df = 1, $0.05 < p < 0.10$); hence, we can form the usage type: red or white bowl. Similarly, the yellow-red and the white jars occur with the same frequency at the 5% level of significance ($X^2 = 0.07$, df = 1, $0.85 < p < 0.90$) and so we can form the usage type: yellow-red or white jar. Next, the yellow-red and white ladles occur with the same frequency at the 5% level of significance ($X^2 = 0.62$, df = 1, $0.35 < p < 0.40$) and so we can form the usage type: yellow-red or white ladle.

We note in addition that the jar/ladle ratio for the jar and ladle usage types for each of the red and yellow-red/white clay colors is the same at the 5% significance level ($X^2 = 0.015$, df = 1,$0.85 < p < 0.90$), suggesting that the jars and ladles form a "tool kit," possibly with the ladles used to remove contents from the jars. If so, the color of the clay may not be important for differentiation among the jars and ladles. We can test this hypothesis by using the red/(yellow-red + white) frequency count ratio for bowls to see if the frequency of red jars and ladles is determined by what appears to be the overall frequency of red clay to yellow-red + white clay. The proportion of red to yellow-red+white clay color for the jars and ladles matches the ratio for bowls at the 5% significance level ($X^2 = 0.60$, df = 2, $0.75 < p < 0.80$). Taking all of the above into consideration, we can rewrite Table 4.9 as Table 4.10 and conclude that bowls are either made with red or white clay for one kind of activity or with yellow-red clay and then used in a different activity, whereas jars and ladles are indifferent to clay color. In addition, jars and ladles form a tool kit.

Table 4.10: Usage Types Derived from Table 4.9

		Color			
Form		Red/White	Red	Yellow-Red	White
Bowl		303*		1601	
Jar				768*	
	Tool Kit				
Ladle				29*	

* Usage type based on frequency counts.

We also note that while the frequencies of the red and white bowls are not statistically different, the X^2 value is close to being significant at the 5% level (unlike all of the other X^2 values). Hence, we should leave open the possibility that red bowls and white bowls may be differentiated by some other criterion. Redman (1978) comments that the percentage of white ware decreases over time and the decrease appears to be due to a change in the percentage of bowls in the site, which suggests that the similarity in the frequency of the red and white bowls may be fortuitous and there are no usage types for the bowls; that is, the red bowls and the white bowls are each a type.

Patterning on Individual Entities versus Patterning in the Aggregate

These two examples again illustrate that a statistical definition for a type based on frequency counts is incorrect. Though "nonrandom association" of attributes is intuitively appealing as the form for a type definition, translating this definition into statistical association of variables—or even a variant such as the attribute combination that is most frequent in a multi-way contingency table—is not valid. By nonrandom association is meant something like the presence of attribute *A* and attribute *B* on the same artifact is due to the artisan choosing to link *A* and *B* on that kind of artifact as opposed to, say, the attribute *A* is first made part of the artifact and then the artisan "randomly selects" a second attribute, *B*, from among all possible attributes for another dimension that could also be embedded on the artifact. The first scenario implies that we would only find the attribute combination *AB* and not some other attribute combination, say *Ab*; the second scenario implies that each of the attribute combinations *AB* and *Ab* would occur equally frequently (allowing for sampling error), assuming we have evidence that the artifacts brought forward for analysis were only made in accordance with this scenario.

The two scenarios are distinguished when identifying usage types. The first scenario corresponds to the case where the usage type is also defined by the attribute combination AB. The second scenario corresponds to the case where the usage type is defined by the attribute combinations AB and Ab. Hence, the notion of nonrandom combination of attributes identifies usage types, not types. Further, the second scenario—though couched in terms of variable independence—is just saying that the artisan is indifferent to the order in which he or she produces artifact types defined by the AB combination, as opposed to types defined by the Ab combination. There is no difference in outcome between one artisan who makes equal number of AB and Ab types by randomly choosing between B and b when making an artifact, and another artisan who also makes an equal number of each artifact type by first making AB artifact types and then making Ab artifact types. For the first artisan, the two variables that measure, respectively, what the artisan does first and what the artisan does second when making the artifact are independent variables. For the second artisan, the two variables are dependent variables where the dependency pattern switches after half the artifacts are made. In neither case does the notion of variable association relate to the definition of an artifact type. Both artisans are making two types: the AB type and the Ab type.

Attempts to use statistical methods of variable association as a means to determine nonrandom combinations of variable attributes also introduced a complication that was not recognized at the time, and is still problematic when using quantitative statistical methods for analyzing archaeological and anthropological data (Read 2005a). Statistical methods are designed for representing patterning observable over a population of entities but not for the individual entities in the population. Statistical methods are not needed for representing patterning that can be observed on a single entity. Similarly, statistical inference methods are designed to generalize from sample data to the population from which the sample data were drawn when the patterning is only observable in the aggregate and not on each individual case. However, a type definition is based on patterning observable on individual entities—a combination of attributes on an artifact. Failure to recognize this disjunction between the assumptions of statistical methods and type definitions has made it appear erroneously that statistical methods could provide an objective and even automatic way to classify artifacts (see de la Vega 1970; Lerman 1970; Regnier 1970; Gunn and Prewitt 1975; Lagrange 1992)—the topic of the next chapter.

5

Objective Classification: Goals and Problems

In American archaeology, "objective classification" arose in conjunction with the "New Archaeology" and initially had the goal of replacing intuitively formed typologies by typologies based on explicit procedures grounded in objective measures. A more far-reaching goal, though perhaps more implicit than explicit, was to arrive at a culturally meaningful classification by objective means. If this could be done successfully, then archaeology would have a powerful method for addressing not only space and time reconstruction of cultural systems, but also the broader issues summarized in the notion of archaeology as anthropology. Objectively determined types and typologies that were culturally salient could be mapped independently onto space through the site-based method of data recovery and onto time through direct dating of the antiquity of sites.

The push in the 1970s for more objective ways to sample space through incorporating sampling techniques developed by statisticians (e.g., Mueller 1975) had the potential of working out cultural boundaries over regions too large to survey in their entirety, coupled with dating sites through direct dating supplemented by time sequences for the appearance and disappearance of artifact types. The objectively determined types could become the analytical units for an archaeological systematics (cf. Dunnell 1971) that would relate artifact material to the cultural domain for researchers focusing on the ideational side of human systems, or to cultural materialism for those focusing on the material side of human systems.

Objectivity Through Statistical Methods

As discussed in the previous chapter, one approach to making classifications more objective was to introduce statistical methods that could implement the concepts archaeologists had about the processes underlying the pattern and structure observed in the data of the archaeologist. A related way was to provide a more explicit foundation for typologies otherwise formulated by intuitive methods by using broad criteria, such as objectively measured patterning of attributes having space and time significance (Whallon 1972). Yet another, and controversial, way to make analysis more objective arose from the New Archaeology's presumption that archaeology had been proceeding without an adequate theoretical foundation for the interpretations that were made of the data obtained through site excavations and regional surveys. The New Archaeology was to be self-consciously scientific; by science was usually meant the view of science promulgated by logical positivists such as Hempel (1965), Braithwaite (1953), and others.

In its extreme form, science became—for some of the new archaeologists—a search for "laws of behavior" (Fritz and Plog 1970; Gould 1978) or "laws of cultural processes" (Binford 1965) that would serve as the basis for explanatory arguments. Less extreme versions of the New Archaeology still relied heavily on a material framework that viewed behavior and culture primarily as adaptations to the conditions (physical and social) within which individuals and groups of individuals acted. From a methodological viewpoint, the organization of the primary data of archaeology needed to be placed on a firmer foundation than simply the "feel" an experienced archaeologist obtained from familiarity with one's data, and this often meant application of statistical methods.

For the purpose of constructing typologies, Spaulding had viewed statistical methods as a way to implement archaeological ideas about the structuring processes that underlie the patterning discovered by the archaeologist. Though his use of attribute (variable) association confounded the notion of a type with the frequency with which activities involving the type may have occurred (as discussed in the previous chapter), the underlying premise that statistical methods are a way to extend archaeological reasoning remains intact. His notion of a type was not defined by statistical methods; he considered that "a good type is a material reflection of a more or less discrete culturally patterned segmentation of human activities" (Spaulding 1982: 19). The methodological problem he attempted to address lay in the means to implement that concept. A similar problem arose later when Binford and Binford (1966) attempted to use factor analysis to discern what they referred to as tool kits from archaeological assemblages. The implementation of the tool kit concept via factor analysis was methodologically flawed through not taking into account heterogeneity in data sets, but the underlying concept of tools associated together because of their use in the performance of a task was neither dependent on—nor defined by—the validity of the implementation (Read 1989a).

Numerical Taxonomy

For other archaeologists (e.g., Clarke 1968; Thomas 1972; Doran and Hodson 1975; Cowgill 1982), the firmer foundation for classifications was to be provided by numerical taxonomy. Conceptually, numerical taxonomy—as it was developed in biology by Sokal and Sneath (1963: 2)—seemed to be ideal for the task. Archaeological typologies were constructed by sorting artifacts into groups that showed internal cohesion and external isolation, and the latter is precisely the criterion that underlies the methods of numerical taxonomy (Doran and Hodson 1975). Consequently, proponents of objective classification borrowed heavily from the methods of numerical taxonomy, especially the clustering algorithms used to implement the basic concept of numerical taxonomy as a way to form groups that showed internal cohesion and external isolation. But the implementation of the internal cohesion/external isolation criterion in numerical taxonomy methods does not necessarily lead to groupings of artifacts generated through the production of artifacts by artisans.

While the notion of "internal cohesion and external isolation" is not foreign to the concept of a type construed as patterning displayed over a set of attributes, for the purposes of numerical taxonomy, it was primarily used as a way to select a method for subdividing data points into groups (or clusters) in the measurement space determined by the variables measured over the entities in question. The meaning the phrase might have for artifact types thereby became defined by the methods of numerical taxonomy, which became—for its archaeological proponents—a new way to define what constitutes a type: "The essence of a type, (or class, or cluster) is discreteness or modality shown by some units relative to others" (Doran and Hodson 1975: 172). Modality could be based on a single variable; hence, a type could be determined using a single variable, or it might only be observed when several dimensions are considered simultaneously. A type would be based on the groupings found by the method of numerical taxonomy (Doran and Hodson 1975: 158) and thereby a type definition would allegedly escape from the limitations of its earlier, intuitive foundations.

The shift from defining a type through patterning of attributes to clusters of data points found in an n-dimensional space (formed by the set of n measures used to characterize the artifacts being analyzed)

reflects a major shift in ideas about what constitutes patterning for the purpose of defining a class in an artifact typology.[1] The premise that a type should be defined in terms of patterning among attribute values allows for class definitions based on patterning that can be observed on a single object without necessary reference to other similar objects. In contrast, the methods of numerical taxonomy are based on a notion of patterning observed in an aggregate of entities and where the patterning cannot be observed on a single object. In effect, the shift is from analysis that does not require statistical methods for implementation of a class definition to analysis that does require statistical methods.

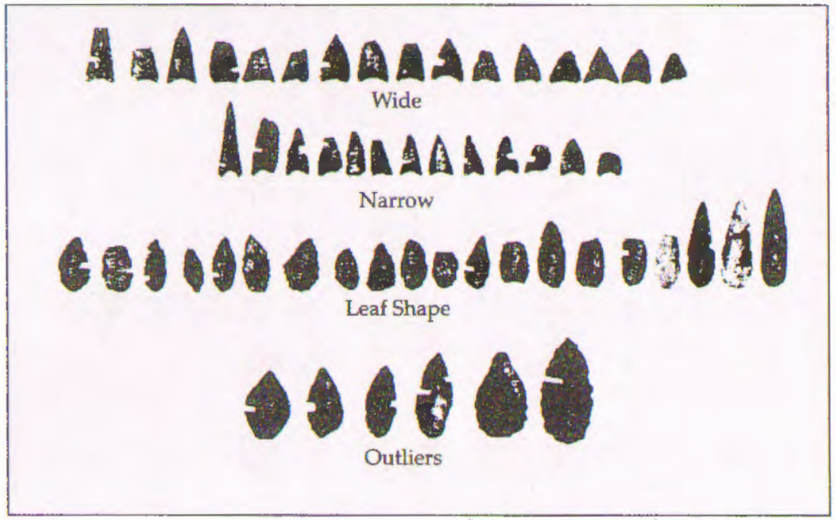
Individual Item Type

We can illustrate the difference in how types may be defined by considering the difference between patterning observable on individual entities and patterning that can only be observed when considering an aggregate of entities. Intuitive typologies are largely, if not exclusively, based on patterns that can be observed on individual entities. A type defined, for example, as Desert Side-notched points refers to projectile points with a triangular shape and notches on the sides of the triangle used for hafting the point to the shaft of an arrow. No statistics are needed to classify an arrowhead found in the Great Basin with a triangular shape and notches in the side of the arrowhead as Desert Side-notched. The definition is based on two attributes: one having to do with shape and the other with the notching. The pattern, triangular shape, is a property exhibited by the arrowhead—either it has a triangular shape or it does not—and notching is also observable on an individual specimen. We do not need to compare the specimen in hand with other projectile points to determine if our point has attributes consistent with the class, Desert Side-notched. Call this an *individual item type*. Now contrast this definition with a quantitative distinction that can be made among the triangular, but not side-notched arrow points found at the southern California Paleo-Indian site known as 4VEN39 (see Figure 5.1). These points can be classified as Cottonwood Triangular points.

Population-Based Type

The concave-based points at 4VEN39 can be separated unequivocally into two groups based on the width of the points (as will be discussed in detail in Chapter 8). The distinction between the two groups derives from a frequency distribution for the width of the points that has the form of a bimodal distribution with no overlap in the two modes. On the

Figure 5.1: Projectile points from 4VEN39. Top two rows are the concave-based points divided into Narrow and Wide points. Bottom two rows are the leaf shape points. Notches are scars from thin sections taken for hydration dating. Some projectile points are missing. Modified from Read 1989b: Figures 3.4 and 3.5



basis of this distribution, we can posit that two classes of triangular points—Narrow and Wide—were made by the inhabitants of 4VEN39. We can provide a definition for each of the two classes by using parameter values that characterize the two populations of points made (or potentially made) by the artisans at this settlement. One population of points corresponds to the narrow group in the bimodal distribution; the other population corresponds to the wide group in the bimodal distribution. Assuming the two populations have an approximately normal distribution (as is true for the sample data), we can define the two type classes through the population mean and population variance for each population.

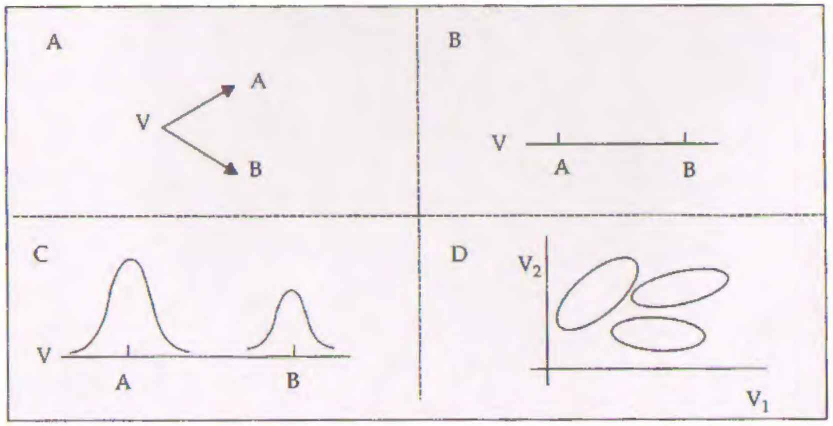
Based on these class definitions, we can assign an individual specimen to a class by comparing its width value to the frequency distribution for the Narrow or Wide points. Contrary to the Desert Side-notched example, we cannot assign a point to a class, Narrow or Wide, without reference to the distributions used to define these classes: the qualitative attribute Narrow is assigned to a group of points and does not correspond to the width of an individual point. A point is not Narrow in terms of an attribute value measured on the projectile point, but in terms of its placement in a frequency distribution. Call this second kind of type a *population-based type*.

Kinds of Dimensions and Type Definitions

Absolute Qualitative and Qualitative Dimensions

The shift to population-based types is approximately the difference between focusing on qualitative attributes versus quantitative measures for the definition of classes. The term "approximately" is used deliberately due to the fact that qualitative differences vary from truly qualitative differences to differences that are qualitative as a consequence of decisions made by the artisans. A difference such as that between a jar without a handle and a jar with a handle is a truly qualitative difference; from a topological perspective, the former cannot be transformed into the latter by remodeling the clay without punching a hole in the clay to make the hole of the handle. Thus, there is no smooth topological change that will transform a jar without a handle into a jar with a handle, and so the two kinds of jars cannot be represented with the same dimensions.[2] Call a variable whose values express topological differences an *absolutely qualitative dimension*. A type definition based on an absolutely qualitative dimension identifies qualitatively distinct different attributes that can be identified on an artifact (see Figure 5.2 A).

Figure 5.2: Schema for four kinds of type definitions: (A) type defined by qualitatively different attributes A and B for a variable V; (B) a quantitative variable V has been bifurcated into two values, A and B; (C) a quantitative variable V can be nominalized in accordance with nonoverlapping modes in a histogram for V; (D) modes can be distinguished only through considering two or more quantitative variable simultaneously



Geometric differences are also based on qualitative differences, but differ from topological differences in that the difference refers to the

geometry of a form (such as the different ways the base portion of a projectile point may be designed or the difference in form between plates versus jars). Geometric differences need not be topologically different. Common to geometric differences is the lack of any clear, single metric dimension along which the differences can be expressed. We will consider geometric differences to represent qualitative, but not absolute qualitative, differences when one geometric form can be topologically transformed into the other.

Bifurcated Quantitative Dimension

Now contrast absolute qualitative and qualitative differences with the qualitative pattern for the temper used in clay in the Southwest. In some regions, tempering may either be sand or sherd but not a blend of the two tempers. Tempering the clay can thus be viewed as having two attributes, sand temper or sherd temper. Nonetheless, we can transform the clay temper attribute into the sherd temper attribute by changing the proportion of sand and sherd temper in the clay—as occurred with Awatovi (Hopi) pottery (Smith 1962). Thus, the characterization of the clay by the two attributes, sand or sherd, simply refers to the extreme points of a single quantitative dimension, proportion of sand (or sherd) temper. If we form a histogram for the proportion of sand temper in the pottery, we will obtain an extreme form of a bimodal distribution in which only two values are represented.

The extreme form of the distribution is due to decisions by the artisans about adding temper to the clay. We can now define a nominal, qualitative variable with attributes sand temper and sherd temper to characterize their decisions. Which of the two states, sand temper and sherd temper, represents the artisan's decision can be observed on a single object without reference to a population of objects. We will refer to this as a *bifurcated quantitative dimension* (see Figure 5.2 B).

Nominalized Quantitative Dimension

The example of Narrow and Wide triangular projectile points from 4VEN39 provides yet another instance of a qualitative difference based on an underlying quantitative dimension. The bimodality permits defining a nominal/qualitative dimension with values Narrow and Wide for the two modes that have been discovered empirically. Further, the fact of a bimodal distribution for a dimension (such as the width of the projectile points) arises from artisan decisions since width values between the two modes could have been manufactured but were not.[3] We can refer to this

as a *nominalized quantitative dimension* (see Figure 5.2 C) and types can be defined by the parameters μ (mean) and σ (standard deviation) that characterize the modes for the variable V (assuming a normal distribution for the frequency of values in a single node). Alternatively, the types can be defined nominally by labeling each of the modes—for example, Narrow and Wide for the two modes for the projectile points.

Rouse's notion of a mode versus attributes and Krieger's argument for relating types to time and space are relevant for a nominalized quantitative dimension. The two widths of projectile points are distributed across the site and throughout the time period for the site, suggesting that all the artisans at the site shared the same notions about what constitutes the modal values for the width variable. In Rouse's terms, the dimension, width, has cultural relevance and the width attributes, Narrow and Wide, are modes. The spatial and temporal distribution provides evidence that the bimodality may have cultural relevance and is not related simply to artisan idiosyncrasy; that is, Narrow and Wide points at 4VEN39 are types and not varieties.

Modally Complex Dimensions

Finally, we can consider a distribution for which there are statistical modes in an underlying continuum, but the modes cannot be expressed as values on a single dimension that appears to have had cultural saliency. In Figure 5.2 D, three clusters of points are apparent but the clusters cannot be characterized by bi- or trimodal distributions along either of the two dimensions used to represent the data. In this case, the modality in two dimensions implies that artisans are favoring some portions of the two-dimensional space over other portions, but without any evident structure among the clusters of data points. Data of this sort might occur with artifacts from different sites where the artisans of each site independently utilized a restricted portion of the two-dimensional space of possible values for the dimensions of the artifacts. Call this a *modally complex dimension* (see Figure 5.2 D). Types are defined by the population parameters (e.g., μ_1, μ_2, σ_1, σ_2 and σ_{12} when there are two variables, V_1 and V_2) that characterize each of the clusters.

Of these five kinds of dimensions, the fifth is the one that has been used to justify using numerical taxonomy as a way to form groups upon which class definitions would be formed. As noted by Hodson, "Attempts to discover approximate modality . . . [in] continuous variables . . . cannot succeed if the patterning is multidimensional, which is the general assumption in carrying out a multivariate analysis" (1982: 25). The first part of Hodson's comment is valid only for data matching modally complex dimensions, since data in this form cannot be expressed in terms of attributes taken as values along single dimensions that had cultural saliency. The second part of his comment is misleading, though, with its implication that multidimensional patterning always corresponds to modally complex dimensions. Multidimensional patterning can occur with absolutely qualitative dimensions, relative qualitative dimensions, and/or nominalized dimensions, which means that we need to consider how methods advocated for formulating typologies in an objective manner relate to patterning in the data.

Although numerical taxonomy methods have been advocated as a general way to form groups that would serve as the basis for defining classes, this goal has one major shortcoming—its implicit assumption that the space in which clusters are to be found is equivalent to the multidimensional space determined by the variables selected for measurement. Numerical taxonomy was supposed to be objective since it made no assumption about what to measure and instead used a catholic approach of including any and all variables. Rather than arguing about what constitutes an attribute versus a mode (or even if the distinction is valid), one would simply include all variables. The methods of numerical taxonomy supposedly did not require initial variable selection and its proponents even rejected variable selection on the grounds that most often there was no clearly stated objective basis for selection of variables (Sokal and Sneath 1963). Thus, simply increasing the number and variety of measurements made on objects would allegedly resolve the possibility that a crucial dimension or aspect might be missed.

Intuition and Numerical Taxonomy

The redundancy of multiple variables would be resolved, it was assumed, through the computation of a similarity measure that would be the basis for constructing groups satisfying the internal cohesion/external isolation criterion. Yet despite the goal of objectivity, intuition was not eliminated since the proponents of numerical taxonomy assumed—but did not demonstrate—that using more variables and some form of distance measurement in the multidimensional space determined by those variables would increase the accuracy with which similarity between objects could be measured and hence the validity of the groups that were identified could be determined. As Doran and Hodson commented, "[I]t would be expected that the more attributes [variables in their terms] included, the more significant any type would be and the simpler the

total classification" (p. 167). Although never explicitly stated, the underlying assumption was that as the number of variables increased, clustering methods should converge on the underlying groups representing types supposedly embedded within the data set brought forward for analysis.

Another way intuition came into play was through a change in how a class would be defined when the class definition is based on attributes. One of the key concepts underlying the methods of numerical taxonomy was a shift from monothetic to polythetic class definitions. A monothetic definition of a class involves a specified list of properties or attributes an object must have in order for the object to be a member of a class. The classes making up paradigmatic classifications are a canonical form for monothetic class definitions. A polythetic definition of a class posits that an object would be a member of a class when it exhibits a sufficient number of attributes from some set of possible attributes, but no specific subset of attributes is necessary for class membership.

In a biological context, the rationale for a polythetic definition of a class (such as a particular species of organisms) reflects the biological reality that not all members of a species shared the same attributes, since attribute variation reflects genetic variability within a species as well as phylogenetic differences between species. The rationale for the polythetic definition in the case of artifact types was not made explicit; instead, the biological argument that polythetic classes are "natural" and monothetic classes are "artificial" was taken over uncritically by proponents of numerical taxonomy such as Doran and Hodson (1975: 160). In an archaeological context, the distinction makes sense for the type/variety system since the varieties of a type shared features that determined the type but varied from the type by attributes that may have been idiosyncratic with respect to the artisan. A monothetic definition could define a variety and a polythetic definition based on some of the attributes displayed on at least one of the varieties could define the type. Each variety would be a type variant by virtue of attributes specific to that variety but not shared with other varieties of the same type. One could still define the type monothetically, though, by restricting the definition to those attributes that are shared across all the varieties and are thus characteristic of the type.

Monothetic versus Polythetic Class Definitions

While the type-variety example illustrates how the distinction between a monothetic and a polythetic class definition might be implemented in an archaeological context, the distinction in the context of numerical taxonomy was primarily used to justify measuring similarity between objects based on the proportion of overlap in attributes. In practice, groupings were based on a similarity measure that might encompass both quantitative and qualitative values—hence likely to make the similarity measure polythetic. Nonetheless, the relevance of the difference between monothetic and polythetic class definitions for artifact classes has not been adequately explored. In addition, what constitutes a sufficient proportion of the attributes for a polythetic definition of a class has no theoretical basis, and consequently polythetic class definitions do not have the preciseness of monothetic class definitions.

Conceptually, the shift from monothetic to polythetic definitions is a shift from identity between objects via exact match of attributes to similarity based on degree of shared features or properties between objects. With a monothetic definition, two objects that are members of the same class exhibit precisely the attributes that constitute the definition of the class. In contrast, with a polythetic definition, two objects that are members of the same class need only exhibit overlapping sets of attributes and the overlap need not be the same for all pairs of objects in the class. Thus, class membership is based on degree of similarity between objects rather than identity. Further, different definitions of similarity can be constructed for the same objects and choice of a similarity measure is often subjective.

Cluster Formation

Regardless of how similarity might be defined, the groups are typically formed by an iterative procedure that can be described as follows. Begin by considering each object to be in a group with that object as its only member, so initially there are as many groups as there are objects. At each step in the analysis, use the value of the similarity measure for objects to decide which pair of already existing groups should be combined together to form a new group to be composed of the members of the two groups being combined together. The choice of groups to be combined together is usually based on the two groups that are most similar at that stage in the analysis. The analysis ends when all objects are members of a single group. Clusters are then determined by selecting a step in the process of forming groups for which the groups identified at that step appear to be "internally coherent and externally isolated."

Similarity Measure

Although the similarity measure between objects can be used directly for comparing groups when each group has exactly one member, a modification of the similarity measure is needed to measure the similarity between groups when a group has more than one member. For example, the similarity of the groups could be the average of all the similarity

measures between an object in one group and an object in the other group. Or it might be the minimum of that set of values, rather than the average. Yet other definitions have been suggested. There is no agreed upon "best" measure of similarity between groups when one (or both) groups have more than one object; hence, the choice of a similarity measure between groups is subjective and intuitive.

Different choices of similarity measures and different choices of the degree of similarity used to define groupings can lead to different and even contradictory results. Each similarity measure is based on assumptions about the internal structure of a cluster such as whether it is circular or oval (in two dimensions), whether the points are more dense near the "center" of the cluster, and so on. In the absence of adequate underlying theory about the expected characteristics of clusters for the domain from which the data are drawn, it is not possible to objectively validate the results obtained using the methods of numerical taxonomy. Instead, intuitive criteria about the coherency of a solution—such as clusters formed at earlier stages in the clustering procedure using a high similarity value are likely to be more coherent and "real" than clusters formed at a later stage using a low similarity value—are often utilized. "Breaks" in the pattern for the formation of groups at each step in the clustering procedure might be used for deciding on the degree of similarity that is relevant for forming groups. Consequently, one may need to try a variety of algorithms to see if there is consistency across different clustering algorithms.

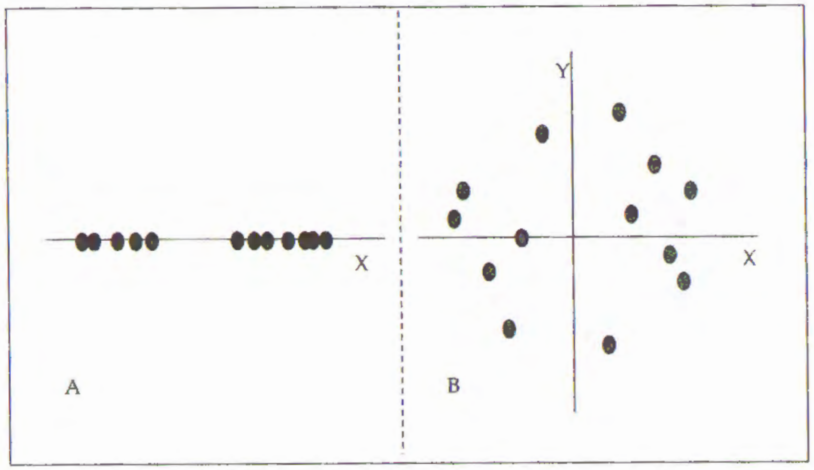
In situations where one has a priori evidence for the number of expected clusters, clustering procedures such as *k*-means clustering can be used that allow for reassigning cases to clusters as the clustering proceeds as a way to see if a more coherent solution can be obtained. This method obviates some of the problems with unconstrained clustering, but there is no assurance that the "correct" clusters will be found even when the right number of clusters is specified (see Appendix).

Convergence Assumption

The fundamental underlying problem with the numerical taxonomy method for the formation of groups to be used for class definitions is straightforward. The proponents of numerical taxonomy have assumed that so long as one has measured the dimensions along which groups satisfy the internal cohesion/external isolation criterion, other variables and dimensions included in the set of variables used in the analysis will not obscure those groupings. However, a simple example will show that this is not the case and a detailed proof is provided in Appendix A.

Consider Figure 5.3 A in which two groups form a clear, bimodal distribution for a single variable, X. The two groups satisfy the internal

Figure 5.3: (A) Two nonambiguous clusters for a single variable *X*. (B) Scattergram plot of the data in (A) with a second variable *Y* for which the values are independent of the clusters in (A)



cohesion/external isolation criterion when we measure similarity by Euclidean distance between points. Now suppose we add a second variable, Y, but for this variable the objects do not have a bimodal distribution corresponding to the two groups in Figure 5.3 A, and so the second variable is statistically independent of the data clusters based on the first variable. This implies that, with regard to the second variable, points along the first variable are now moved randomly some distance up or down from their location on the first variable. We now have a scattergram plot as shown in Figure 5.3 B. But in this plot, a pair of points (such as the top two points) from the two different groups may have greater similarity (as measured by Euclidean distance between the points) than two points from the same group. As we add more dimensions, the breakdown of internal coherence and external isolation becomes worse. Hence, rather than converging on the correct subdivision of the data set as additional variables are added, the opposite may occur.

Methods such as principal components analysis (SPSS 2003), which have been used to reduce redundancy among variables by finding the subspace in which most of the variability in the data is located, may or may not remove the distorting effects of the "extra" variables. If most of the variability is within the reduced space in which the groupings are apparent, then principal component analysis may be effective, but there is no a priori reason to assume that less variability in the data occurs among the "extra" variables than among the "correct" variables (i.e., the variables determining the space within which the groups show internal cohesion and external isolation).

For data whose underlying structure is in the form of a taxonomy rather than a paradigm, the problem is further compounded by the different subspaces within which groupings may be located. The measurement of similarity takes into account all of the variables that are part of the data set and embeds the data into the high dimensional space determined jointly by these variables. Even if the problem of extraneous variables is not present, the combined space may still obscure the way in which the data form a taxonomic structure and the distinct groupings will not be found by the methods of numerical taxonomy. Nor will the methods of numerical taxonomy indicate that the underlying structure has not been recovered. The latter is a serious problem.

The methods that come under the rubric of numerical taxonomy do not permit the results to be tested for goodness-of-fit—as can be done with a statistical model—since there is no a priori distribution that a cluster solution should satisfy. Consequently, there are a plethora of methods, each using a different criterion for how one might implement the concept of internal cohesion and external isolation. The lack of an adequate model for way the data in question are structured contrasts with statistical methods such as regression analysis, for which one postulates a model that specifies the distribution pattern that should be exhibited by the data if the model is valid. The typical assumption for regression analysis is one of normally distributed residuals (difference between the data value and the corresponding model value) with constant variance in the residuals across the data set. Failure to match the anticipated pattern for the distribution of the residuals implies that a new model needs to be formulated. But cluster procedures lack a satisfactory model against which cluster results can be assessed. While there are some methods (e.g., the pseudo t^2 statistic [SAS 1989] used by Read and Russell 1996) that have been developed to give a sense of whether groupings identified using a clustering algorithm are in fact distinct, one cannot assess whether the clustering has failed to identify groupings in the data that satisfy the internal cohesion/external isolation criterion.

This does not mean that clustering procedures are not useful. When a clustering algorithm separates out groups that clearly satisfy the internal cohesion/external isolation criterion, the groups so distinguished are valid. For example, if the variables measured on the artifacts are the (x, y) coordinates for the location of the artifact in a site and we obtain clearly distinguishable clusters from the clustering algorithm, the clusters will also be spatially segregated on the site. The problem lies more with results that are not clear cut or even indeterminate. We do not know if the failure to find groupings is due to the homogeneity of the data or to data being patterned in a manner for which clustering algorithms are insensitive. Christenson and Read (1977), for example, found no clusters in the 4VEN39 projectile point data when the original nine variables that had been measured on the projectile points were used in a clustering algorithm called Neighborhood Limited Classification.[4]

Relevant and Appropriate Variables

The failure to find distinct clusters in the 4VEN39 data set contrasts strongly with the fact that the points have a clear division between concave-based and convex-based points. When naive subjects (undergraduate students in several courses) were asked to sort pictures of the points into groups, it only took about 5–10 minutes for them to sort the points into at least two distinct groups: concave- versus convex-based points. As Adams and Adams (1991) would put it, when the points are spread out on the table, a division of the points into concave- versus convex-based points is immediately obvious and intuitive sorting outperforms a clustering algorithm based on the variables as originally measured. Though Hodson (1982: 22) suggested that the failure to find these two obvious groups lies with the choice of clustering algorithm, none of the clustering algorithms available in the Statistical Package for the Social Sciences (SPSS 2003), for example, sorts the points into concave- versus convex-based points.[5] Even when *k*-means clustering is used and two groups are specified, there is still substantial error in the clustering solution. Hodson also suggested that the failure to find clusters may be due to the fact that "inappropriate variables have been chosen" (p. 23), but this begs the question of whether we know the appropriate variables in advance and ignores the fact that one of the variables measures the degree of concavity or convexity for the base edge of the points.

What constitutes appropriate variables is a nontrivial question and one that is critical to the objective formation of a typology (to be discussed further in the next chapter). Robert Whallon (1982) argued that determining the relationship of variables to data structure may be more important to the construction of typologies than the particular methods that are employed and that we need to better understand "the nature of the relationship of . . . variables to the typology (or structure) inherent in the data" (p. 130). Like Rouse's distinction between attributes and modes, Whallon distinguished between the variables as measured by the archaeologist and the dimensions relevant to the phenomena in question: "Conceptually . . . it is important to distinguish between *variables* in terms of which we measure and describe archaeological materials and *dimensions* which underlie our typologies" (p. 130). If so, then the question arises as to how one determines those dimensions on the basis of the variables that have been measured. One argument is that if the variables have "captured" the dimensions that are relevant to how the

archaeological materials are structured by artisans, then the variables should relate to each other in the same manner as their relationship to the underlying dimensions. For example, if size is a dimension with cultural salience, so that objects are made according to size categories, then variables that relate to size—such as length, width, height, and the like—should co-vary with each other but not with variables that relate to a different dimension that varies independently of size. This other dimension might be surface treatment of pots, for example. If surface treatment is independent of size, then variables that measure surface treatment should not co-vary with variables that vary with size.

Dimensionality Reduction

The pattern of some variables co-varying with each other but not with other variables underlies statistical procedures for dimensionality reduction such as factor analysis (mentioned earlier in this chapter) and principal component analysis. Briefly, principal component analysis (and factor analysis) determines—within the space represented by the set of variables measured over the artifacts—the dimensions along which most of the variability in the data occurs. The first principal component is defined to be that single dimension (or axis) in the space of measurements along which the greatest amount of variability occurs in comparison to any other single dimension. The first principal component need not be one of the variables that was measured. The second principal component is the dimension perpendicular to the first dimension along which the second greatest amount of variability occurs, and so on. Principle component analysis allows for the original set of measurements to be replaced by values along the dimensions distinguished in the manner just described, and in so doing one can often reduce a multivariate space to a two- or three-dimensional subspace within which most of the variability in the data can be displayed.

This method of dimensionality reduction was used by Christenson and Read (1977) to reduce the original set of nine variables measured over the projectile points to two principal components that captured most of the variability in the original set of nine variables. When these principal components were used in lieu of the measurement variables, clustering procedures showed unequivocal separation of the points into two groups—one corresponding to the concave-based points and the other to the convex-based points. In fact, the first principal component alone could be used to separate the points into these two groups. In effect, the first principal component was measuring the dimension of "concavity," a dimension directly and indirectly measured by several of the original variables. However, as Christenson and Read also note, there is no assurance that the method of principal components will always isolate relevant dimensions.

The difficulty relates to the problem identified earlier regarding homogeneity of data sets. The method of principal components assumes a homogeneous data set in which each data point is the consequence of the same process(es). Principal component analysis assumes that the data have a joint normal distribution in the space of measurements (i.e., a distribution of points where the highest density of points is at the center of the distribution and the density falls off smoothly (and normally) in all directions as one moves away from the center of the distribution). This method determines the primary dimension for the joint normal distribution along which most of the variability in the data occurs, then a dimension perpendicular to this dimension along which most of the remaining variability in the data occurs, and so on. But a joint normal distribution for the data points is equivalent to saying that the entities being measured form a single group with no subgroup satisfying the internal cohesion/external isolation criterion. However, because most data sets brought forward for analysis for constructing a typology are structured in the form of groups and subgroups, the data violate the basic assumption of principal component analysis.

In the case of the projectile points from 4VEN39, the principal component analysis did find appropriate dimensions for reasons that are partially fortuitous. The concavity of the base is a culturally salient dimension for the projectile points; for each projectile point, the artisan made a decision either to make the base convex or concave. The bimodality arising from this decision process ensures that the variability in the data along this dimension is substantial and hence a dimension likely to be determined by principal component analysis.

If the data structure were in the form of three distinct groups in a two-dimensional measurement space, rather than bimodal in a one-dimensional measurement space, then there may be no single dimension in the two-dimensional space along which the groupings can be found (see Figure 5.2 D with three ellipses elongated in the same direction but separated from each other). Heterogeneous data sets of this kind have two sources for variability: (1) variability within groups and (2) variability between groups. A method such as principal component analysis cannot disaggregate the two sources of variability; it will produce dimensions that are a mixture of these two sources of variability and thus dimensions that may relate neither to structure within groups, nor to the relationships between groups.

For example, a principal component analysis done on eleven measurements of jars, pitchers, and bowls from the Swiss Late Neolithic site of Niederwil (see Figure 5.4) yields a single component that accounts for

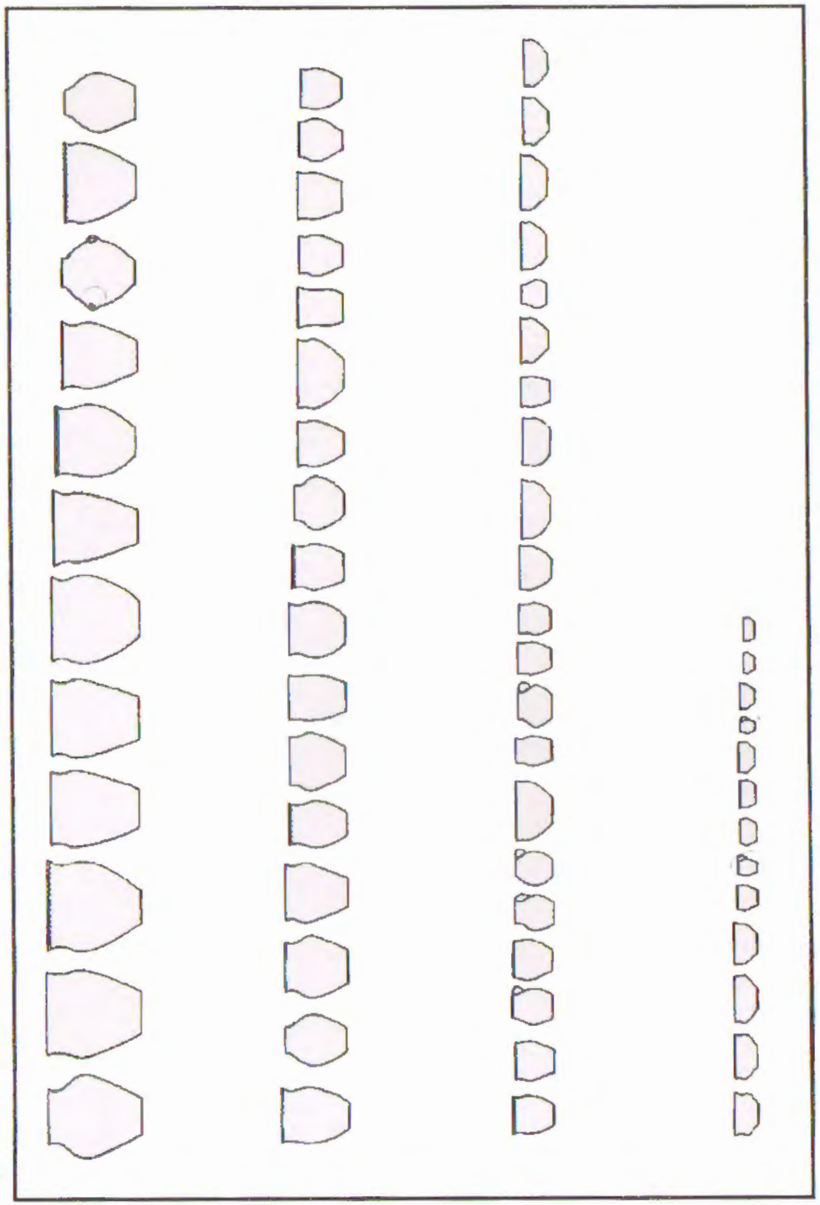


Figure 5.4: Outlines of pottery vessels from the Swiss Late Neolithic site of Niederwil

about 83% of the variability in the data.[6] No other principal component satisfies the commonly used criterion of an eigenvalue of 1.0 as the cutoff point (Whallon 1982: Figure 6.5, p. 145).[7] The single principal component is roughly a size dimension and use of this dimension alone to represent the pottery objects obscures the evident shape variation among the vessels (see Figure 5.4). The single principal component mainly reflects the fact that the set of variables contains multiple measurements of size, and so variation in the data set is largely one dimensional due to redundancy in the measurement of size. Groupings of pottery objects with shape differences would not be identified were a typology to be based solely on this principal component. As noted by Whallon, "The use of principal components . . . should be far from routine in application" (p. 133).

Variable Redundancy

Redundancy among variables should not be a difficulty, according to the advocates of numerical taxonomy methods, so long as the set of variables has jointly measured the relevant aspects of the vessels. The validity of the outcome of numerical taxonomy methods, however, depends on assuming that these methods are robust with respect to variable redundancy along the relevant dimensions. For the Niederwil pottery, the profile can be recovered from the measurements made on the pottery; hence, relevant dimensions are embedded within the suite of measurements.

When Whallon used a clustering algorithm (Ward's method of variance minimization) based on all the variables, eleven groups could be distinguished. These groups differed both in terms of size and shape, but shape variation within some of the groups was clearly heterogeneous (p. 148) and these groups were not satisfactory. Thus, while the clustering based on the variables as measured provided a rough sense of the way the vessels could be separated into groups reflecting possible types, some of the groups were inappropriate for defining vessel types (see Whallon 1982: Figure 6.7).

Whallon then formed clusters based on the first and second principal components using the pattern for the frequency distribution for each of these two components. The frequency distributions suggested a possible partition of the components into four nodes for the first principal component and three nodes for the second. This allowed Whallon to define a paradigmatic classification with twelve cells based on the possible combinations of the modes of the two components. In the paradigmatic classification, three cells were empty. As with the cluster analysis, the paradigmatic classification provided only a rough outline for a possibly typology. Some of the groups had considerable shape variability and there was only partial agreement between the groups found using cluster

analysis and the groups determined from the intersection of nodes. Whallon concluded that neither of these procedures—based on the variables as measured—produced satisfactory groupings upon which a typology could be constructed.[8] Both grouping procedures did, however, highlight the importance of size and shape in forming groups for these data.

Size and Shape

Since size and shape appeared to be two salient dimensions for the vessels, Whallon constructed a shape measurement based on the ratio of the neck diameter to the height of the neck from the base, and this ratio clearly distinguished shape classes that could be identified from a scattergram plot of neck diameter versus height of the neck. Size was then taken to be the cross-sectional area at the maximum diameter of the vessel. Much clearer modes were evident for this dimension; based on modes in the size and shape variable (four for each variable), a paradigmatic classification with sixteen cells was constructed for which four had zero values. Whallon considered this typology to be much more satisfactory as all of the groupings were reasonably homogeneous (1982: 155).

The dimensions of size and shape used by Whallon were constructed from some of the variables measured over the pottery objects. There appeared to be two important dimensions for identifying size and shape variation in these vessels. Modality in their frequency distributions was much more pronounced than for the components found in the principal component analysis. This fact, and the much greater homogeneity in the groupings determined by the combination of modal values using these two dimensions, imply that the constructed dimensions are measuring aspects of the pottery salient to the artisans in the production of these vessels. The clear contrast between the initial typologies (determined by using cluster analysis and principal components) and the typology based on the dimensions that appear to be salient for the artisans implies that "the identification of underlying dimensions and measurements along them are . . . the critical state, because it is on the degree to which we can or cannot directly measure along these underlying dimensions of variability that the choice for all further analytical methods and techniques ultimately must be based" (1982: 160).

Whereas Rouse and others made the selection of variables a primary task by distinguishing between attributes and modes, the proponents of numerical taxonomy have presumed that one can simply expand the set of variables measured over the objects to ensure that the set of measures includes the information that otherwise would have been obtained from modes. The numerical taxonomy methods assume that increasing the

number of variables used for determining object similarity will lead to convergence on inherent groups in the data brought forward for analysis, which would then be the basis for class definitions. This assumption is the flaw in numerical taxonomy methods: the inclusion of variables that have no bearing on the embedded groupings to be used for type definitions does not lead to convergence but to divergence from groups with internal cohesion and external isolation (see the Appendix for a mathematical proof of this conclusion).

6

Artifact Measurement

Criteria for measuring artifacts in a manner relevant to artifact classification have not been discussed extensively in the literature. Individual researchers have reported on their measurement systems (e.g., Bonnichsen 1977; Dibble and Chase 1981; Thomas 1981; Andrefsky 2005), including pre-computer digitization methods for taking measurements (Benfer 1967; Gunn and Prewitt 1975; Burgess and Kvamme 1978; Dibble and Bernard 1980), but the relationship between choice of measurements and type formation (e.g., Binford 1963; Benfer and Benfer 1981; Whallon 1982) has not been widely discussed. Comments that authors have made about measurement and formation of types are often less a prescription for what one should measure than platitudes or generalities—such as that measurements should be done systematically to permit meaningful comparison of artifacts (Deetz 1967), the connection between measurement and typologies is not clear cut (Sheets 1975), and the choice of variables is framed by the researcher's cultural heritage (Voorrips 1982: 113)—or even based on invalid assertions, such as that there is no connection between types and quantitative variables (Adams and Adams 1991: 88).

Cultural Salience

Striking in these comments is the lack of attention placed on measuring aspects of artifacts that have cultural salience and/or the means for determining if a measurement has cultural salience. The *relevance* of cultural salience for measurements has been noted by a number of authors. For example, Tugby (1958) makes the comment that his study of axes from Australia "amplifies this view in regarding the type as an assemblage of features perceived by the makers as desirable. . . . [T]he ideal would be the use of traits which have been established by ethnological enquiry as being *perceived to have value by Australian aborigines*" (p. 24, emphasis added). But, he notes, the axes are not part of the ethnographic present and such

an inquiry is not possible. Lack of an "ethnographic present" for artifact material does not obviate, though, the need to distinguish from among all possible aspects of an artifact those that should be measured in order for types based on these measurements to have cultural saliency. Some researchers, however, have simply sidestepped the issue by assuming that qualitative differences are culturally determined and therefore the only critical issue is the method for discerning qualitative attribute combinations that had cultural salience (Dunnell 1986).

The relative abundance of qualitative attributes for pottery in comparison to lithics has led to greater use of qualitative characteristics when defining pottery types (Shott 2003). With pottery, many of the qualitative attributes that are routinely distinguished by researchers also represent a choice made by the artisan. Dichotomies such as decorated/not decorated or slipped/not slipped surface finish refer to design choices in the making of pottery and hence were dimensions of significance to the artisan. However, not all choices made by the artisan were modes; some of the choices may be specific to a particular artisan. Nor do all qualitative distinctions that can be made constitute decisions.

The connection between a decision by the artisan and the resulting attribute on the one hand, and the decision by an artisan and its cultural context on the other, provides a way to link a qualitative aspect of an artifact with its cultural context by asking how artisan decisions relate to her or his cultural context. How to link quantitative measurements to cultural context is less clear, though, since numerous quantitative measurements can be made of the morphological and physical aspects of an object—yet only a relatively small proportion of all possible quantitative measurements had cultural salience.

Variables versus Dimensions

The distinction between what one chooses to measure quantitatively and which of these measures had cultural saliency was considered by Whallon (1982) in some detail, as discussed in the previous chapter. Whallon extended to quantitative variables the qualitative distinction between an attribute selected by the archaeologist for his or her purposes and an attribute that has cultural saliency by making a useful distinction between "*variables* in terms of which we measure and describe archaeological materials and *dimensions* which underlie our typologies" (p. 130, emphasis added). He means by dimension an aspect of an artifact that had cultural salience (much like Rouse's notion of a mode). The definition of a dimension may be based on more than one quantitative variable and hence

need not be measurable directly on an artifact. For example, shape for artifacts having a rectangular geometric form can be defined by the ratio between the height and width of the rectangle; hence, the shape is measured indirectly. If shape were relevant to the definition of a type, then shape would be a dimension in Whallon's terms.

As with Rouse's argument about modes, this approach leaves unanswered how we identify dimensions relevant to the definition of a type prior to knowing the types. The argument can easily become circular, as when a blade versus a flake is defined by a blade having a length greater than twice the width (Bordes 1961; Sheets 1975; Honegger 2001) and then one assumes the distinction between a blade and a flake had cultural saliency.[1] The problem of circularity was partially addressed by Whallon (1982) through requiring that types, when based on quantitative variables, be based on modes (in the statistical sense) determined through discontinuities in the values along a posited dimension. Though he did not state it explicitly, the underlying presumption is that the discontinuities represent choices made by the artisan and hence have cultural saliency to the extent that the artisan's choices reflect the cultural community within which the artisan is embedded.[2] Whallon went on to suggest that a typology can then be defined paradigmatically by the intersection of the modes found in each of two or more dimensions (p. 138), contradicting Adams and Adams' (1991) claim that typologies cannot be constructed from quantitative variables.

The dimensional distinction, as Whallon recognized, presumes that the variables selected for analysis account for the underlying—though initially possibly unknown—dimensions upon which a typology should be based. We would like such an underlying dimension, once it is recognized, to be constructible from the variables that are in fact measured. We will refer to this criterion as *measurement sufficiency*.

Measurement Sufficiency

Advocates of numerical taxonomy have advocated addressing measurement sufficiency through an exhaustive set of measurements. But as discussed in the previous chapter, numerical taxonomy methods are not robust with respect to variables that do not reflect underlying discontinuities in the data based on dimensions that had cultural saliency for the objects in question. Hence, addressing measurement sufficiency by taking an exhaustive set of measurements still leaves an important question unanswered: what should be the dimensions through which artifact types are defined?

Another means by which measurement sufficiency can potentially be addressed is through appropriate theory that identifies the relevant

dimensions (cf. Borillo 1977; Redman 1978). Whallon considered this possibility, and though he noted the work done by Wobst (1977)—which suggested, for example, that items with high visibility are more likely to signal group affiliation than items with low visibility—he concluded that in most areas we lack the requisite theory needed to identify the relevant dimensions. While there are areas other than signaling group affiliation where relevant dimensions have been identified, such as items requiring considerable labor investment being more likely to signify higher status or to be part of status competition in resource procurement than items that are easily obtained (Gero 1989; Aldenderfer 2006, based on the arguments of costly signaling theory [Zahavi and Zahavi 1997]), Whallon's cautionary remarks are still valid.

Qualitative Shape Measurement

From a practical viewpoint, absent an adequate a priori basis for translating measurement sufficiency into practice, we may sort artifacts by criteria that appear to have cultural saliency. Some of these criteria relate to material categories underlying standard artifact categories such as lithics, pottery, basketry, bone tools, woven materials, and so on. These material-based categories separate artifacts according to differences in physical properties; since it is problematic for one kind of material object to be substituted for an object made with a different material, they are likely candidates for culturally salient distinctions as well.

Within material categories, we can identify additional categorizations based on aspects of shape that are also likely to have had cultural saliency. By the fact of artifacts being material objects, they have a particular shape. But only certain aspects of the shape of an artifact are relevant to the artifact being included as a member of a culturally salient category. One criterion for this kind of assignment relates to aspects of shape that reflect "deliberate modification" during the production of an artifact. Deliberate modification means decision making on the part of the artisan as to the morphological properties that are to be part of the finished artifact. If those decisions were not simply artisan specific but reflected shared notions of what constituted appropriate morphological form, then the modification had cultural saliency.

While we cannot a priori distinguish what aspects of shape had cultural saliency, we can begin with shape differences that are purely qualitative and then proceed incrementally to a more quantitative level for shape differences, on the grounds that qualitative differences in shape depend on decision making by the artisan and are likely to be aspects of artifacts that make it problematic for artifacts to be substitutable for

each other—as should be true of artifacts grouped together in the same category. For example, a jar without a handle is qualitatively different in shape than a jar with a handle. The former may require the use of both hands to pour contents from the jar, whereas pouring can be done with the latter using just one hand; hence, jars without handles are not substitutable for jars with handles when the mode of pouring (with one or two hands) is a relevant aspect for an emic categorization of jars.

We will begin the argument with topological differences (such as jars with handles versus jars without handles), then allow for geometric differences in shape, and finally consider quantitative differences in shape. For this sequence of kinds of shapes, we need to distinguish between the shape of an artifact (by virtue of it being a material object) and those aspects of the material shape that arose through deliberate modification of the artifact as a whole—or in part—during the production of an artifact.

> Definition: *The constructed shape of an artifact refers to the idealized form represented by those portions of the artifact that were deliberately modified as part of the production of the artifact from raw material.*

By idealized shape is meant a smoothed form of the shape for which variation from the smoothed form appears to simply reflect variation due to the production process, and not variation in the perceived shape.

Constructed Shape: Topological Shape Differences

The primary topological properties relevant to artifact form refer either to the boundary of the artifact or to the overall form of the artifact (boundary plus enclosed surface). Topological properties include whether the form contains holes and, if so, how many. A bowl and a jar without a handle or spout are topologically equivalent: the former can be changed into the latter while the clay is malleable without tearing or breaking the clay. A jar with a handle that encompasses an opening is topologically equivalent to a doughnut, since the former can be molded into the latter without tearing or breaking the material. Topological properties of this kind can be characterized by the number of holes embedded in the form.

Embedded holes occur primarily with pottery rather than lithics due to the nature of the material and differences in the respective production methods. Stone knapping is primarily a reduction process, which does not change the topological properties of the object unless the removal process introduces a hole into the object (such as when one makes a bead). Pottery production is amenable to introducing topological differences since the clay can be easily torn or broken and reconnected so as to introduce a hole, or pieces added to the clay object that encompass a hole—as occurs with the addition of a handle to a clay pot.

Topological differences in artifact forms have implications for quantitative measurement systems satisfying the archival property. An outline with embedded holes will require a measurement system for the boundary of the embedded holes, for example. Even topologically equivalent outlines may require different submeasurement systems when the outlines are geometrically different.

Constructed Shape: Geometrical Shape Differences

Although triangular points and Desert Side-notched points are topologically similar, a measurement system designed for triangular points will not measure the notch of the Desert Side-notched point without adding additional measures for the notch portion of Desert Side-notched points since the two kinds of points have different geometries. By geometric differences within topologically equivalent outlines will be meant differences in the geometry of an outline due primarily to corners. Circles (or variants on a circle such as an ellipse or oval) differ from polygons through a circle being a (regular) geometric shape without any corners, whereas polygons have corners formed by the intersection of adjacent sides. We can distinguish among circular outlines and polygonal outlines by the number of edges (which may be straight or curved) and corners. A triangular point has three sides and corners and differs geometrically from a side-notched point through the latter having eleven corners (three for the overall triangular shape and four corners for each of the two notches, assuming the notches are based on rectangles).

Geometric differences expressed in terms of corners may often be due to specific steps in a production process, such as adding a notch to a triangular projectile points. Not all geometric differences due to corners, however, arise from choices made by the artisan in the production of an artifact—especially with the production of lithic artifacts. A flake removal from a core may have an outline with corners due to the mechanics of the flake removal process, rather than the corner being a feature of an outline introduced directly by the artisan in what otherwise would be an outline without a corner.

From a production viewpoint, a corner involves a discontinuity. As one moves along a smooth curve (or line) without corners toward a corner formed by the intersection of two curves (or lines), the curvature of the smooth curve either is not changing (as in the case of a curve that is a portion of the boundary of a circle) or is changing in a smooth manner. The curvature at a point along a curve can be expressed through the radius of a circle whose circumference is tangent to the curve at that point, and change in curvature can be represented by change in the radius of a circle whose circumference is tangential to the curve as one moves along the curve. A corner contrasts with an edge through the qualitative property

that there is no single tangent line at the corner, and so the corner has no single curvature. Whereas edges are produced through more-or-less smooth and continuous production processes, a corner represents the intersection of two such processes and hence requires—in a production process—control over how the two processes will intersect and thereby produce a corner. Corresponding to our hierarchy of qualitative differentiation, we make the distinctions given in Table 6.1.

Table 6.1: Hierarchy of Qualitative Distinctions

Distinction	Example
Topological	
Point	Tip of piercer
Line segment	Working edge of a utilized flake
Closed curve	Outline of projectile point
Disk	Plate
Sphere	Hammerstone
Torus	Jar with handle
Geometric	
Point (Number of corners)	Tip of piercer (0 corners)
Line segment (Number of corners)	Working edge, utilized flake (0 corners)
	Serrated edge (many corners)
Closed curve (Number of corners)	Agate Basin point (3 corners)
	Scandia point (5 corners)
	Scottsbluff point (7 corners)
Disk (Number of edges)	Plate with curved bottom (1 edge)
	Plate with flat bottom (2 edges)
Sphere (Number of edges)	Hammerstone (0 edges)
	Core with striking platform (1 edge)
Torus (Number of holes in the torus)	Jar with 1 handle (1 hole)
	Jar with 2 handles (2 holes)

Measurement Sufficiency Based on Geometric Dimensions

One way to address measurement sufficiency is to identify an underlying geometry for the artifacts in question (e.g., Rau 1876; Fowke 1896; Wilson 1899b; Strong 1935; Finkelstein 1937; Adams 1940; Whiteford 1947; Newell and Krieger 1949; Bullen 1975; Vierra 1995) and then take a suite of measurements characterizing that geometry. Dibble and Chase (1981) have used this method to classify Paleolithic handaxes by referring to a series of types based on idealized geometric forms.

An earlier paper by Black and Weer (1936) elaborated on this method for classification by addressing the relationship between what is measured and the artifact classification. They worked out a system of classification based on first identifying the "basic geometric form of a given object; and then, secondly, to describe its *deviation or modification* from this basic form with the least possible amount of description" using the criterion "How may this object be most briefly described in a manner that will be readily understood by others?" (p. 281, emphasis added). While the latter quote appears to suggest that a classification is defined through its communicative use among researchers, their classification was nonetheless grounded in dimensions that (they argued) had saliency for the artisan. They viewed variation in the geometry of artifacts to arise from modification of a basic geometrical form by the artisan through a sequential, conceptual process going from an initial geometric form to the final geometry of the finished artifact.

More recently, van der Leeuw has used the same theme in his characterization of three conceptual structures—topology, sequence of steps in a shaping process, and partonomies (the parts of an artifact)—that underlie an artifact tradition. Like Black and Weer, van der Leeuw expresses the topology of an artifact in terms of a transformation from a basic geometrical shape by asking, "[I]s the shape viewed as the transformation of a sphere, of a cone or of a cylinder?" (van der Leeuw 2000: 70).

The value of Black and Weer's geometric approach as a means for characterizing the shape of an artifact was largely ignored by subsequent articles on artifact measurement, though Chenall (1967) is an exception. Nonetheless, one only has to contrast the clarity of Black and Weer's geometrical characterization of shapes with a potential connection to the conceptual sequence of the artisan, going from general idea to specific form, with a subsequent article by Whiteford (1947) to see the problem that arises with measurements made in the absence of a clear connection between what is measured on an artifact and the structuring processes that underlie the properties and form of the artifact. Whiteford wanted to introduce precision in the recording of information about artifacts that would enable "such a complete and accurate description of each artifact that typing and analysis would be possible from the catalogue card without necessitating the repeated handling of each artifact" (p. 229), yet the resulting description is "not easily translated into a mental image of the artifact" (p. 235). In other words, even a minimal requirement such as being able to recover the outline of an artifact from the measurements made on the artifact was lost under the guise of precision.

Black and Weer recognized that not all artifacts have an underlying geometry, particularly artifacts that appear to be crudely made. They initially made a division of artifacts into "C-Crude, B-Finished, A-Exceptional" (p. 291). By finished and exceptional, Black and Weer seemed to have in mind artifacts for which the shape in question was produced in its entirety by the artisan—not lithics whose shape is a consequence of flake or blade production coupled with modification aimed at producing a working edge. The latter would result in forms that neither fit into the crude category nor can be reasonably characterized as modifications of a

basic geometric shape, since the flake need not have a simple geometric shape. Nonetheless, their argument highlights two measurement issues related to formation of types. (1) Is the goal of measurement to provide a means for characterizing the shape of an artifact as a whole? And (2) should all objects deemed to be artifacts be assignable to a type? We will consider each of these questions in turn.

Shape Measurement

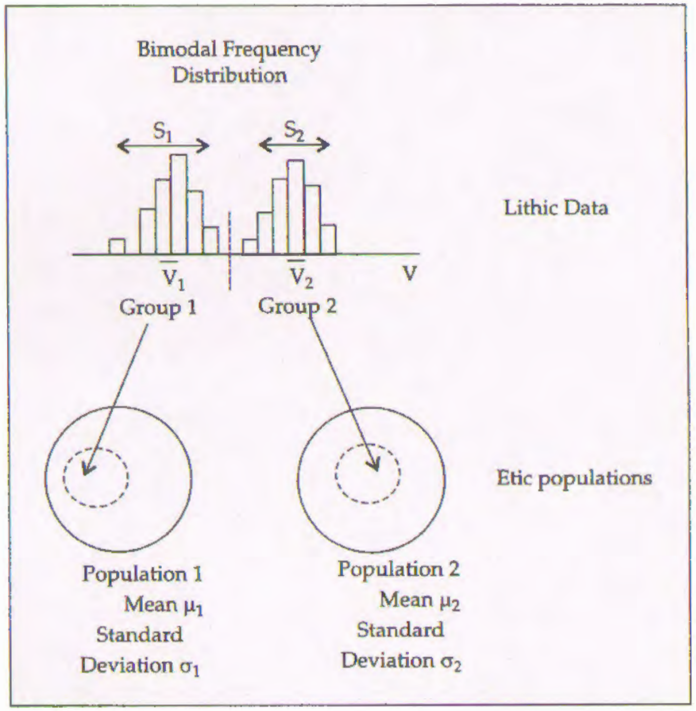
One important goal for shape measurement is to provide a numerical characterization of a shape that can be linked analytically to criteria for class definition and membership. The problem with carrying out this goal is twofold. First, the quantitative aspects that are useful for class definition are not known in advance; and second, the quantitative attributes of the shape that should be measured may lack an adequate theoretical foundation for identifying them or may bear an unclear analytical relationship to criteria for class definition and membership. Many metric measurements are selected simply on the basis of aspects of shape that are assumed to have universal (or near universal) validity, such as the width and length of a lithic artifact viewed as a two-dimensional object.[3]

The critical step in identifying coherent artifact classes from a set of measurements lies in forming groups of artifacts that are internally homogeneous and externally isolated. The internally homogeneous criterion implies that each group member can be considered to be an outcome of the same underlying process(es) that gave rise to a group's distinctiveness. Hence, for an internally homogeneous group, one group member can be substituted for another group member with respect to those processes. The external isolation criterion is the basis for asserting that the group differences are "real" in the sense that objects with measurement values outside the range (or ranges) of measurement values for the data located in the groups are nonetheless theoretically possible. In other words, any "gaps" in the distribution of measurement values for the data in hand stem from the fact that the range of observed values reflecting the production of the objects in question has been constrained. For artifacts, the "external isolation" may relate to decisions by the artisans with regard to the range of values that will or will not be allowed in the production of artifacts—that is, to a range of values that may have cultural salience.

That an internally homogeneous/externally isolated group can be seen as a statistical sample from the members of a class of artifacts makes possible a way to provide class definitions from group characteristics. The link from group property to class definition is provided through parameter estimation based on sample measurements, where the parameters—in

conjunction with the shape of the frequency distribution for the population (such as a normal distribution)—characterize the population for which the group may be considered to be a sample (see Figure 6.1). For a population with a variable having a normal distribution, the two parameters μ (population mean) and σ (population standard deviation) determine the specific normal distribution for that population.

Figure 6.1: Relationships among a bimodal distribution used to identity artifact groups, the populations for which the groups are samples, and the parameters characterizing the populations



The parameter values can be estimated from the properties of the group viewed as a sample drawn from a population of all possible artifacts of a given type, as will be discussed below. For example, if two groups are distinguished by a nonoverlapping bimodal frequency distribution for a metric variable V over some collection of artifacts, the variable group mean $\bar{v}$ measured over the objects in one of the two groups, along with the standard deviation s measured over the same objects, may be used to estimate the population parameters μ and σ for the population of all possible artifacts of that type for which the group of artifacts in hand may be considered a sample (see Figure 6.1). When more than one variable is used

to determine the internally homogeneous/externally isolated groups, the set of parameters will include not only the mean and standard deviation, but also the covariance between each pair of variables.

The population distinguished in this manner is initially an etic population based on the frequency distribution of the artifacts for the variables measured over the artifacts brought forward for analysis. It is an etic population since there is no a priori reason to assume that the set of measures for the artifacts has included precisely the dimensions that were culturally salient in the production of artifacts. In addition, the class defined in this manner may be the union of several emic classes when the variables used in the analysis only represent some of the dimensions along which differentiation was made by the artisans in the production of artifacts. Consequently, the class may be without direct cultural significance. In this case, we can say that the culturally salient dimensions are under-determined by the variables that have been measured. Contrarily, the variables that have been measured may over-determine the culturally salient dimensions when the variables jointly measure not only those dimensions, but also measure other aspects of the artifact that did not have cultural salience.

Under-determination of the culturally salient dimensions cannot be resolved simply by increasing the number and variety of variables measured over the artifacts since, as discussed in the previous chapter, methods such as clustering algorithms for constructing groups lose their discriminatory power with the addition of measurements whose distribution is not structured in accordance with groups in the data for which there is internal homogeneity and external isolation. Nor can over-determination of the culturally salient dimensions necessarily be resolved through statistical methods for dimensionality reduction, since these methods typically assume linear relations among the variables and do not distinguish within-group from between-group variation in the measurement values. Dimensionality reduction properly applies to homogeneous, not heterogeneous, data sets. But the required homogeneous data sets are not known a priori and so statistical methods for dimensionality reduction will be biased to the extent to which between-group variation exceeds within-group variation.

As a first approximation to resolving the under- or over-determination problem, we need a nonredundant and sufficient list of variables whose measurement values completely characterize a given shape. With such a set of variables, we can then determine those aspects of the shape that are dimensions by considering the pattern for the measurement values that should occur for culturally salient dimensions.

To completely characterize a shape means to be able to re-create the shape using only the measurements made over the shape. For example,

length, width, and thickness of a projectile point do not completely characterize its shape. We can formalize this requirement in the following definition.

> Definition: *An ordered* n-*tuple of measurement values* (m_1, m_2 . . . m_n) *completely characterizes a shape without redundancy if (a) there is a set of drawing rules that permits reconstruction of the shape outline using only this ordered* n-*tuple of measures, and (b) there is no ordered* k-*tuple of measures* $k < n$, *such that the shape outline can be reconstructed from the ordered* k-*tuple.*

By *drawing rules* is meant specification of how the shape is constructed from the n-tuple of measurement values. For example, with shapes symmetric about an axis, the measurement values need only relate to the portion of the object on one side of an axis of symmetry since the other half can be drawn by reflecting the measured side across the axis of symmetry. We can also refer to a set of measures that completely characterize a shape as satisfying the archival property: the shape can be reconstructed from the measures that have been taken. The archival property is a weaker requirement than nonredundancy in that a set of measures satisfying the archival property may possibly be a redundant set of measures.

Measurement schemes that have been devised for quantitatively representing artifacts have, with few exceptions, been devised in a more-or-less ad hoc manner based on what the researcher views as the important dimensions of the artifact. But in the absence of an adequate theory for delineating what constitutes those dimensions, the measurement scheme may not satisfy the archival property for the relevant dimensions of the artifact, let alone the nonredundancy requirement. Failure to satisfy the archival property may lead to artifacts being treated as equivalent even though the artifacts differ from one another along aspects of the shape not included in the measurement scheme. Some measurement schemes that have been proposed for measuring artifacts satisfy the archival property but not the nonredundancy requirement, and only a few measurement schemes that have been proposed satisfy the nonredundancy requirement. We can illustrate the issues involved by considering several different measurement systems that have been devised for Paleolithic bifaces known more colloquially as handaxes.

Metric Measurement Systems

By a system of (linear) measurements will be meant a series of measures such as Euclidean distances between pairs of points on an artifact. The points selected for measurement typically include extreme values for

the artifact (such as the maximum length and width of the artifact) and distances to extreme measurements (such as the distance to the maximum width from the tip or base of the object). Where the object has clear geometric properties, such as a circular opening in a pottery object or a triangular shape for a projectile point, measures that characterize the geometry are usually included. Measurement systems of this kind have generally focused not on the archival requirement but instead on the dimensions of the artifact deemed by the researcher to be of importance for distinguishing among artifacts that share qualitative similarity, such as the general shape for the outline of the artifact.

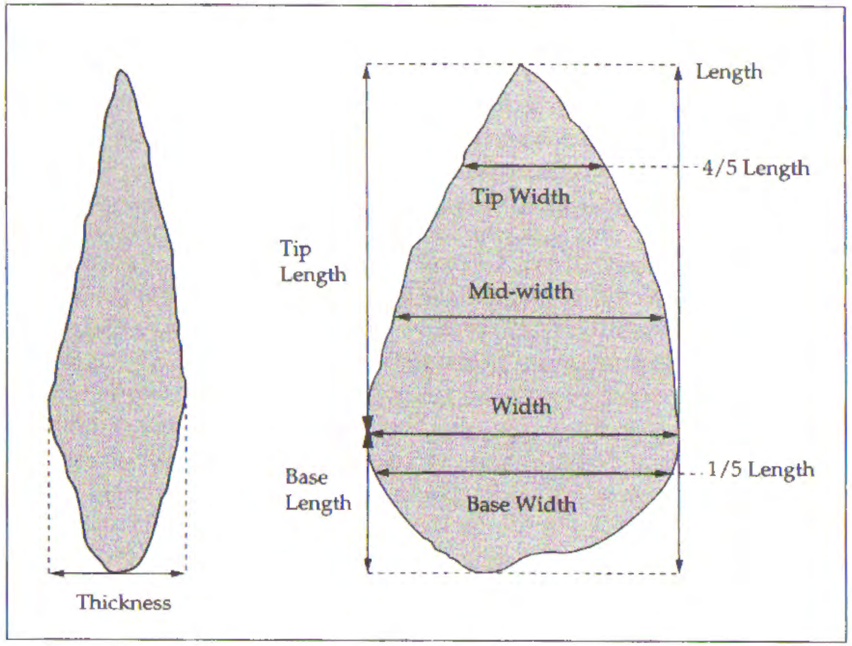
Widths and Width Ratios

For Paleolithic bifaces, two measurement schemes have been prominent—one devised by Bordes (1961) and the other by Roe (1964, 1968). Both Bordes and Roe included a measure of the width of the biface at the midpoint of the major axis. The two measurement systems differ primarily in the choice of additional measures beyond the measures of the extreme values of the biface. Whereas Roe included the width of the biface measured at one-fifth and four-fifths of the distance from the base along the major vertical axis, Bordes only included a third width measure taken at three-quarters of the distance from the base of the biface. Neither included a measure of the angularity of the tip of the biface. McPherron (2003) subsequently combined the two systems of measurement into a single system (see Figure 6.2; see also Goren-Inbar and Saragusti 1996: Figure 8).

This system of measurement does not satisfy the archival property. The vertical distances between the width values are fixed by the location of these measurements on the biface, but the horizontal location of one width value in relationship to another is not fixed. Since the width measurements do not have information that locates one width value horizontally relative to another, each of the four width values can be shifted to the right or left and still be consistent with the set of measures made under this measurement scheme (though overly extreme relocations of the width values would conflict with the technology of biface manufacture). Consequently, there is no way to determine from the measurements whether the biface is symmetrical—and if it is not symmetrical, the degree of its asymmetry (Wynn and Tierson 1990).

If we are only provided with the width values and wish to redraw the biface outline, we would need to assume symmetry as a default condition. If there is a vertical axis of symmetry, then the sides of the biface connecting the first and last width measurements can be redrawn reasonably well from the four pairs of points if we further assume that the sides

Figure 6.2: Measurement system for biface handaxes. Redrawn from McPherron 2003: Figure 1



of the biface are simple, convex curves. But even with the assumption of symmetry and simple convex curves for the sides, the tip and base cannot be redrawn accurately. The distance between tip and base is measured, but neither the horizontal location of the peak of the tip nor the most extreme point of the base is measured; hence, the location of these two extreme points for the biface cannot be ascertained from the measurements. Nor can it be assumed that the tip segment comes to a point as in Figure 6.2 since other bifaces have rounded tips. Similarly, considerable variability also occurs in the morphology of the base portion of bifaces (see Débenath and Dibble 1994: Figures 11.5–11.101).

There is no assurance, then, that two bifaces with identical measurement values will have similar shapes. One could be symmetrical while the other displays substantial asymmetry; one could have a tip segment coming to a point and the other a rounded tip; one could have a base that is wide and relatively flat and the other a pointed based; and so on.

Shape Differences

Instead of satisfying the archival property, Bordes's typology for the bifaces emphasized ratios (referred to as indices) computed from the

measurements and thereby focused on the shape of portions of the bifaces.[4] A similar comment applies to all of the types in the typological scheme that Bordes (1961) devised for Middle Paleolithic tools. His typological scheme focused on the shape of the portion of a tool that was functional, such as the retouched edge, the portion that was either gripped or hafted, or the body of the tool that was unretouched (Bisson 2000).

Bordes's typological scheme fits within a framework that emphasizes attribute patterns rather than the shape of the tool as a whole, in accordance with the now widely accepted perspective that the overall shape of Middle Paleolithic tools need not represent a cognized shape on the part of the artisans (Bisson 2000 and references therein). The overall shape may simply reflect the choice of a flake upon which a retouched edge would be imposed; the shape of the retouched edge and its relation to the shape of the flake is a consequence of the technology of flake production, the intended functional usage of the artifact, how the flake tool might he held or hafted, resharpening, and so on. Or, in the case of the burins that play an important role in the typological organization of Paleolithic lithic assemblages and are also found in Paleo-Indian and Archaic sites in North America (Epsein 1963), a working edge is formed on a flake through the removal of a straight spall from the flake edge using a "burin-blow technique" (Débenath and Dibble 1994; Inizan et al. 1995) that leaves both a chisel-like "corner" and a straight edge (the negative scar of the spall removal) on the flake. Hence, the shape of the tool is simply the mechanical consequence of the morphological characteristics of the flake and the technique used for spall removal. The shape of the burin lends itself (and the spall) to a variety of uses (Inizan et al. 1995) involving scraping, engraving, hafting, or resharpening (Tomášková 2005).

Bordes did not take into account the consequences that these factors may have in forming the attribute patterns upon which his typology was based. A "convergent scraper," for example, may simply arise from a scraper with a single retouched edge through adding a second retouched edge rather than making a new tool, and through resharpening that eventually leads to convergence of the two retouched edges (Dibble 1987, 1995). However, the analysis of end-scraper frequencies in Chapter 9 leads to distinguishing convergent scrapers as a distinct type of scraper, thereby underscoring the need for type definitions based on the results obtained from analytic methods sensitive to distinctions imposed by the producers of the artifacts. These distinctions may include choice of the form of a blank that already has the form of the scraper, and so the form of the tool with retouch may not simply be due to modification of form through usage (Gordon 1993).

Bordes constructed a taxonomic—rather than a paradigmatic—typology for Middle Paleolithic lithics since his definitions of types

were based on a series of attribute and shape distinctions that would be valid for only some of the lithic objects (such as bifaces) and could not applied in any order, as is assumed to be possible with a paradigmatic classification. The first division for bifaces was between flat and thick bifaces (with the division determined arbitrarily, rather than on the basis of modality in a frequency distribution graph). Bifaces were defined to be flat if (maximum width)/(thickness) > 2.35; otherwise, the biface is thick. Flat bifaces were then divided into triangular versus cordiform versus ovate, again using an arbitrary division of ratio values (Débenath and Dibble 1994: 132).

The thick bifaces had a separate division that did not match the divisions made of the flat bifaces; hence, the taxonomic structure for the classification system. The thick bifaces were divided into either lanceolate ("lance-like"), having a cordiform aspect, or pointed at both ends—again with the divisions defined arbitrarily rather than on the basis of modality in a frequency distribution graph.

Bordes's typology is consistent with what Dunnell has referred to as unit formation for measurement based on the idea that "classifications, or measurement scales . . . [are] devices of science that are *imposed on*, rather than extracted from, empirical reality. They function to provide the terms by means of which we identify, describe, measure and compare phenomena" (Dunnell 1986: 152). The distinctions used in Bordes's taxonomic scheme (and in other taxonomic systems such as that of Malmer [1962] for the early Neolithic) are imposed and not based on modalities in metric measurements (Dibble 1984, 1987, 1995; Débenath and Dibble 1994; Bisson 2000) and the typology is a "descriptive typology" that makes possible "comparing and integrating the material from sites that span . . . a wide geographical and temporal spread" (Débenath and Dibble 1994: 6).

However, as an imposed etic typology, it is not amenable to direct interpretation at an emic level since there is no assurance that what is called a type does not crosscut emically valid distinctions that reflect the conceptualizations and distinctions involved in the production of biface artifacts. An etic class defined through imposed criteria is likely to be heterogeneous with respect to emic distinctions in morphology introduced through the production of artifacts. In addition, an imposed etic class may mix technological, functional, and stylistic attributes, a problem that occurs with Bordes's typology (Djindjian 1987; Mellars 1992). Nonetheless, Bordes made emic interpretations of both his types and assemblages characterized by type frequencies expressed in the form of cumulative frequency diagrams.

Bordes considered the types to have cognitive validity and to represent the intentions of the makers of the artifacts (Bordes 1965, 1969; Bordes and

de Sonneville-Bordes 1970). Bordes argued that assemblage groupings based on patterns for the frequency of these types in an assemblage represent the equivalent of ethnic groupings (Bordes 1961). But if a type is to have an emic interpretation, the basis for its definition must arise from distinctions that plausibly have emic validity and not simply from distinctions imposed on otherwise continuous variability (Limp and Carr 1989 [1985]; Read 1989b [1985]). Of the 62 types in the typology devised by Bordes, 23 are kinds of scrapers. Is it plausible to assume that scrapers were cognized in 23 distinct ways, or are the distinctions an imposed dissection of essentially continuous variability, as Ford (1954) argued in his critique of type definitions formulated by the archaeologists of his time? The fundamental problem with the typology devised by Bordes, if it is to have emic validity, lies in the failure to establish that the distinctions upon which it is based have a cognitive basis (Rolland 1981; Barton 1988; Dibble 1995).

Some of the distinctions made by Bordes—when examined against relevant data sets—are found to be differences in a continuum (Dibble 1987; Sackett 1988; Rolland and Dibble 1990; Freeman 1992) and need not represent conceptual or behavioral distinctions on the part of the artisans in the production of lithic tools, and thus are not emically "imposed forms" (Mellars 1991). A similar conclusion has been made for recent Australian implements where what were assumed to be formally different types of scrapers have been shown to represent stages in a reduction sequence, leading to the conclusion that "continuous variation without distinct evidence of 'imposed form' is a pattern present in both early and later stoneworking technologies" (Hiscock and Attenbrow 2002: 248). If a distinction between flat and thick bifaces, for example, is to have emic validity, the criterion for making the distinction must arise from characteristics of the bifaces produced in accordance with that conceptual distinction (such as bimodality in the thickness dimension, or distinctiveness of clusters in a scattergram plot of maximum width and thickness), not from an arbitrary value for the (maximum width)/(thickness) ratio used to define the difference between flat and thick bifaces. Indeed, even if the makers of bifaces in one region did make a distinction between flat and thick bifaces, there is no a priori reason to assume it is a universal distinction made by all makers and users of bifaces; rather, the distinction must be demonstrated on an assemblage-by-assemblage basis.

While it is evident that Bordes's typology needs revision (Bisson 2000 and references therein), the direction for revision suggested by Bisson does not resolve the problem of using attributes that are imposed rather than derived. Instead, under the guise of increased descriptive objectivity, his suggestion of adding attributes derived from nominalization of

quantitative measures simply perpetuates the problem of imposed attributes and attribute values. In his list of attributes for describing flake tools, for example, Bisson includes distinctions such as straight, concave, or convex edges based on a cutoff value of ±0.05 for the concave/convex distinction. But why the 0.05 boundary? Why not 0.04 or 0.06? Or more to the point, unless one can first show a discontinuity in the curvature of edges, the nominalization has no validity except as a reduction of a metric dimension to a three-valued ordinal scale that bears an uncertain (if any) relation to patterning produced through the lithic production process and the subsequent usage of the artifact.

Further, if the makers of the artifacts made a distinction between two different degrees of concavity, simply recording the edge as concave would hide that cognitively valid distinction. Etically imposed nominalization of continuous variation also makes it difficult to measure the degree of correlation between different morphological aspects of artifacts. Expanding on what was already an imposed list of attributes resolves neither the arbitrariness of the attributes used in type definitions nor the archival problem of re-creating the morphology of the artifact—or at least the culturally salient aspects of morphology—from a measurement system for representing the morphology of the artifacts.

Archival Property

The archival problem and symmetry assumption that are part of the measurement system for bifaces can be addressed by increasing the number of width measurements and measuring the distance to each side from a vertical axis, as described by Dibble and Chase (1981). They recognized the importance of a measurement system that could both represent the artifact form accurately and would be a measurement system comparable across a variety of artifacts (and not be specific to just one type of artifact). Their measurement system elaborates on the measurement scheme for bifaces by dividing the width measurements into a left and right measurement so that asymmetry can be accommodated. Increased archival accuracy was achieved by measuring widths along the major axis of the object divided into ten segments (see Figure 6.3). The major axis was determined by the axis of flaking extending from the point of percussion. The axis of flaking formed the y-axis in a rectangular coordinate system and the point of percussion was located at the zero value for the y-axis. Measurements of the distances from y-axis to the outline of the flake were taken, along with the overall length of the artifact. This yielded a series of 22 measurements that characterized the outline of the flake and one measurement that represented the thickness of the flake. The measurement system allows for a reasonably accurate outline to be redrawn from the measurements under the assumption that the curved line segment

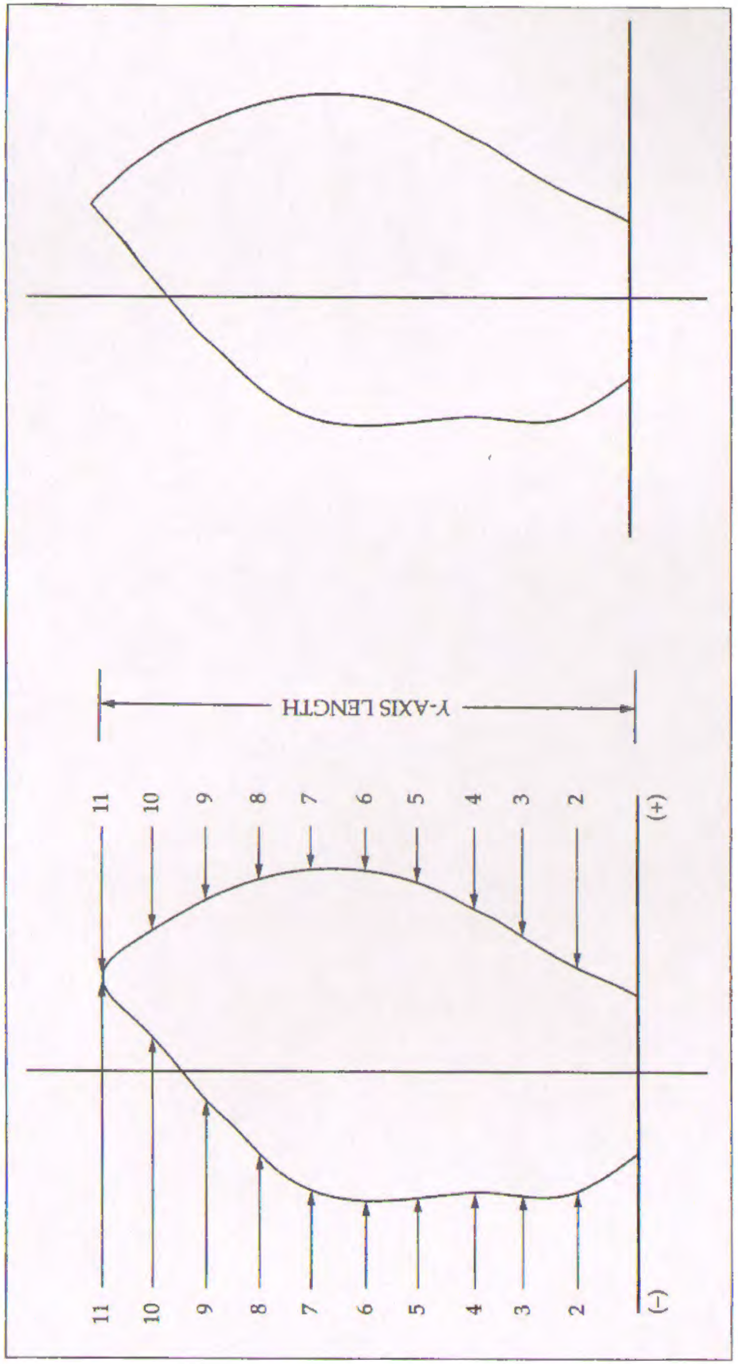


Figure 6.3: Archival measurement system for bifaces on the left and re-created outline on the right based on connecting adjacent measurement points with straight-line segments. Redrawn from Dibble and Chase 1981: Figure 1

connecting pairs of points is relatively smooth and thus can be approximated by straight line segments connecting adjacent points along the periphery of the flake (see right side of Figure 6.3).

The method of measurement is equivalent to a series of points digitized in a Cartesian coordinate system along the boundary of the flake. If the flake has length l, then the width measurements made at equidistance along the y-axis can be expressed by (x_i, y_i), where $x_i = A_i$, $y_i = l\,(i-1)/10$ and $1 \le i \le 11$ for the 11 measurements made on the right side of the flake; and by (x_{i+11}, y_i), where $x_{i+11} = B_i$, $y_i = l(i-1)/10$, and $1 \le i \le 11$ for the 11 measurements made on the left side. The 22 digitized points, (x_1, y_1), $(x_2, y_2), \ldots, (x_{22}, y_{22})$, defined in this manner along the boundary can be converted back to the 11 pairs of width measures, and so the digitized points form a measurement system equivalent to the width measures.

We can consider the width measurements, then, to be a constrained form of digitization. The constraint is given by the interpretation that the distances between pairs of points on opposites of the artifact boundary should be width measurements for the artifact, based on an axis of orientation that determines the right and left side of the artifact boundary. The emphasis on width measurement relates to the ratios constructed from the measurements. Dibble and Chase (1981) used the width measurements to measure the degree of curvature of the outline as one goes from one pair of width values (measured from one side of the flake to the other side) to the next pair by computing the ratio of adjacent width values. The method of comparing the ratio of width values resembles Bordes's use of indices to from a taxonomic typology, but with the added proviso that change in the ratio as one traced along the boundary should also be taken into account.

If the constraint on the location of the points along the boundary is dropped, then the measurement system can be subsumed under digitization of the artifact boundary. Without a constraint on the location of points to be digitized, the digitization can satisfy the archival property to whatever degree of accuracy is desired simply by selecting the points to be digitized sufficiently close to one another. However, though unconstrained digitization resolves the archival problem, it less evident as to how analysis should proceed since digitization does not depend upon variable definition for its implementation—hence leaving unanswered the choice of variables that should be used for identifying distinct artifact classes.

The system of width measurements (with the width measured as a positive or negative amount from the y-axis) has the advantage of reducing some of the measurement redundancy that occurs with digitization along the outline. The redundancy is reduced by embedding the y-values for the measurements expressed in Cartesian coordinate form

as described above into the rule for redrawing the outline and then only keeping track of the x-values. A list of the eleven pairs of width measurements can be converted into an outline from the information that the widths were measured at distances spaced evenly along a vertical line segment of specified length l.

Radial Measurement Systems

The archival criterion can also be addressed through the polar coordinate measurement system introduced into the archaeological literature by Montet-White (1973, 1974; Montet-White and Johnson 1976) with subsequent applications by others to bifaces and projectile points (Kay 1980; Hoffman 1989 [1985]; Wynn and Tierson 1990). Wynn and Tierson applied the method of polar coordinates to bifaces through measuring a series of 22 rays based on imposition of the outline of a biface on a polar coordinate grid system. We will now consider the strengths and weaknesses of this type of measurement system.

Wynn and Tierney standardized the orientation of the biface outline on a polar coordinate grid by aligning the major axis of the biface, defined by a line connecting the tip of the biface with the most extreme value on the base of the biface with the 0°–180° axis of the polar coordinate system. The center of the polar coordinate system was then centered on the midpoint of the major axis (see Figure 6.4, left side), with the larger of the two sides of the biface placed to the left of the vertical axis. The rays were not equally spaced since the greater curvature of the ends of the biface required more closely spaced rays than did the sides of the biface for equal archival accuracy since the degree of accuracy wanted in the redrawn outline depends on the angular distance between the rays. The redrawn biface in Figure 6.4 (right side) based on the measured points provides a fairly accurate representation of the outline of the biface as a polygon. Wynn and Tierney treated each ray as a variable in their analysis of the bifaces.

Polar Coordinate Measurements versus Shape Ratios

The polar coordinate measurement system is based on representing the outline of the artfact with points determined by the intersection of rays from the center of the polar coordinate system to the artifact's outline. The accuracy of the outline traced by connecting the points selected along the outline depends on the curvature of the outline and the distance between points along the outline. For archival purposes, the points need not be equidistant.

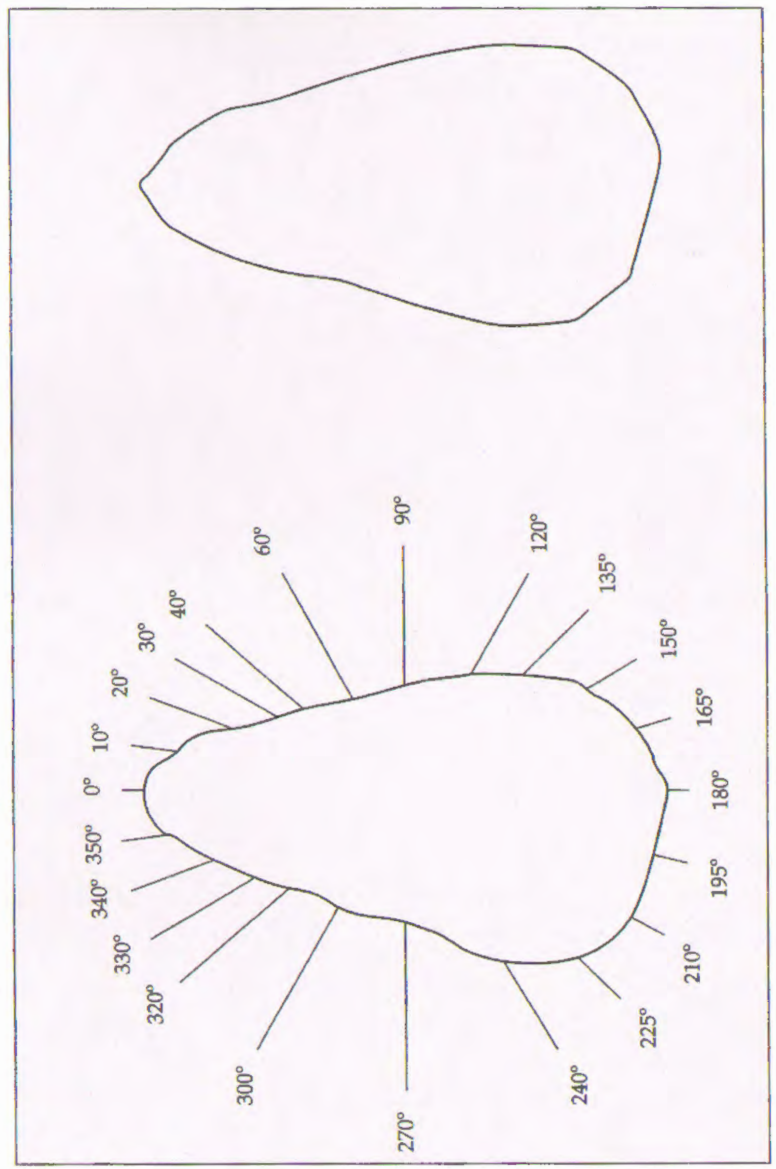


Figure 6.4: Left side: polar coordinate measurement system for bifaces. Right side: outline based on the measurements. Redrawn from Wynn and Tierson 1990: Figure 1

A point on the outline is located by the angle from a reference line and the distance from a reference point (the center of the polar coordinate system) along a ray at that angle to the outline. The primary constraints on a choice for the location of a reference point are (1) the reference point should be comparable for different outlines, and (2) a line from the reference point to the outline should intersect the outline at only one point when the line continues to be extended in the same direction. This makes it possible to consider each ray to be a variable with value the distance from the reference point to the outline along that ray.

Locating the origin of the polar coordinate system at a central point for the outline provides a convenient reference point for outlines that are always convex with respect to a central point since there will only be a single point of intersection of a ray with the outline.[5] For more complicated outlines, such as tanged projectile points, a ray may not have a unique intersection with the outline and so more than one point along the outline will have the same reference angle. Hence, the variable determined by that ray will not have a single value.

By using a fixed set of angles (even if unequal angles), the measurements can be reduced to the length of the rays. The reconstruction procedure for converting the variable measurements to an outline then requires including the sequence of angles as part of the rule for reconstructing the outline.

The polar coordinate measurement system used by Wynn and Tierney and the Bordes/Roe measurement system for bifaces are not directly comparable since the ratios used in Bordes's typology of bifaces cannot be recovered directly from the polar coordinate measurement system. The polar coordinate measurement system does not distinguish any particular aspect of the shape as having likely importance for the production of the bifaces, whereas the approach used by Bordes and Roe presumes that certain shape measures are more useful than other shape measures for constructing a typology for the bifaces. Their presumption is difficult to assess since there is no a priori reason to assume that the ratios based on their choice of width measurements are the relevant emic dimensions for the production of the bifaces. Emic relevance could be justified if the shape differences recognized by Bordes or Roe were due to something akin to the gestalt approach discussed by Adams and Adams; that is, through repeated visual comparison of the bifaces, Bordes and/or Roe became aware that there are consistent shape differences among the bifaces and these shape differences can be measured by the ratios that they defined and then used for constructing a typology for the bifaces. However, the fact that arbitrary cutpoints in the ratio values were used to define categories makes problematic even a gestalt argument as a way to justify the emic relevance of their measurement system. If there are truly different shape categories, in the internally homogeneous/externally isolated sense of category differences, then one should be able to demonstrate multimodality in the ratio values used to define the categories.

The polar coordinate measurement system, in contrast, makes it possible in principle to remove the arbitrary basis for category differences by providing a measurement system that satisfies the archival property when the rays are sufficiently close to one another. This possibility was negated, however, by the way Wynn and Tierney analyzed their data.

Instead of constructing categories from the reduced set of dimensions, they examined whether the bifaces from different geographic regions had different shapes on the average. Though this avoids introducing imposed categories, it introduces a different problem. The mean values for the variables constructed by them are due to two effects: first, the mean values for the dimensions of emically relevant shape categories embedded in the data; and second, the relative frequency of these categories in the different regions. Even if the different regions had exactly the same shape categories for bifaces, say shape categories $S_1, S_2, \ldots, S_n$, a variable V measured over all the bifaces in a region has mean value given by $\bar{v} = w_1\bar{v}_1 + w_2\bar{v}_2 + \ldots + w_n\bar{v}_n$ (where w_i is the relative proportion of category S_i making up the assemblage from the region and $\bar{v}_i$ is the mean value for the variable V_i in that region). Because the value of $\bar{v}$ depends on the weights w_i, $\bar{v}$ can differ between two regions even if the two assemblages are made up of the same artifact shape categories, each with the same mean values for the relevant measurements for these shape categories. Hence, any difference in the overall mean value of V for all of the bifaces in the assemblage between regions can be due to differences in the relative frequencies of the categories in one region in comparison to another region, or due to differences in categories between the regions, or to a combination of both effects.

Apparently, there is a wide/narrow/normal difference in the shape of the bifaces since the four regions considered by Wynn and Tierney (sites in England, Africa, India, and the Middle East) differ in the relative abundance—but not the presence—of each of these three forms. The differences in mean values for the four regions (see Table 6.2) appear to be due to the relative abundance of these three shape forms and not to differences in the form of bifaces among the regions. The reasons for the differences in the frequency of the three forms are not obvious, though it is due partially to difference in material (Jones 1981) and partially to change in the form of bifaces through time (Wynn and Tierson 1990). Any associated chronological differences with the shape differences, however, are not well documented since a wide range of dates is associated with the sites in each of the four regions.

Table 6.2: Shape Differences in Paleolithic Bifaces by Continent

	Middle East	India	Africa
England	6.20	2.70	10.77
Middle East		3.80	15.86
India			2.97

Redundancy in the Polar Coordinate Measurement System

The combination of increasing the accuracy of the representation through increasing the number of rays and then treating each ray as a variable has the drawback that it introduces redundancy into the system of measurements. The polar coordinate measurement system used by Wynn and Tierney determines 22 variables for the analysis simply as a way to represent the shape outline. Similarly, though Hoffman (1989 [1985]) used fewer (16) radial measurements for representing the outline of projectile points, he also measured the edge angle of the projectile point at the intersection of a ray with the boundary of the projectile point for four of these rays and included a thickness measurement—yielding a total of 21 variables. In both cases, the number of variables clearly exceeds the possible number of culturally salient dimensions for the bifaces and projectile points.

The redundancy introduced through the polar coordinate measurement system works against discovery of categories since cluster methods for group identification are not robust with respect to measurement redundancy, especially for aspects of the artifacts that are not directly relevant for expressing the dimensions along which differences in artifacts were introduced in the production of the artifacts. Both Wynn and Tierney, and Hoffman recognized the problem with redundancy in the variable set being used to measure the artifacts and both sets of researchers used similar analytical methods to reduce redundancy in the variable set.

Redundancy Removal Through Analytical Methods

As discussed in the previous chapter, principal component analysis provides a means for removing redundancy. When Wynn and Tierney computed principal components, they found that the first principal component had a high correlation with each of the variables. Since size is a dimension that would cause all the metric variables to increase in magnitude as this dimension increases, it is reasonable to interpret the first principal component as a size-related dimension. Hoffman obtained a similar result for his projectile point data. Wynn and Tierney then modified the raw measures by dividing the measures on a single biface by the length of that biface, thereby changing the raw measures to unit-free measures that represent the length of a ray as a proportion of the length of the biface. Their goal was to characterize the shape of the bifaces separately from the differences in size among the bifaces.

The method of principal component analysis applied to Wynn and Tierney's modified variables reduced the system of 22 variables to four principal components that measured (roughly speaking) variation in the left side, tip, right side, and base portion of the biface. In contrast, Hoffman did not modify the original set of measurements since he was considering the relationship between the size of the projectile points and the angle of the edge of the projectile points. Hoffman wanted to explore the possibility that the projectile point typology for Late Archaic Woodland sites in the Tennessee Valley may be confounding morphological changes due to resharpening with shape differences that may be emically salient. The operating hypothesis was that resharpening should lead to an increasingly oblique edge angle (Ahler 1971; Morse 1971; Goodyear 1974; House and Wogaman 1978) since resharpening mainly affected the width (and length) of a projectile point, not its thickness, and the change in edge angle with size should be continuous and not discrete if the size variation among the projectile points was due to resharpening. In contrast, if the types of projectile points that have been identified are each an emically salient type, then the relationship between edge angle and size should have discrete groupings and should not be continuous (assuming that edge angle and size determine an emically relevant dimension along which there is differentiation among the Late Archaic and Woodland projectile point types in the Tennessee Valley).

In both cases, the analytical goals depend on determining emically salient dimensions from the variables as measured. The method of constructing variables directly from polar coordinate measurements, however, produces variables that are not likely to have emic saliency as measured. Whether the method of constructing principal components from these measures solves the redundancy problem depends on the degree to which the context where the method is being applied is structured in the manner assumed by the mathematical procedure for determining principal components. There are two reasons the latter is problematic, one conceptual and the other analytical. Conceptually, the mathematical procedure is based on the assumption that the structure of the data set is the consequence of a single structuring process; that is, the data set is homogeneous, and not due to the combination of several structuring processes. Analytically, the method assumes linear relationships among the variables that may—or may not—be valid and cannot be assumed but must be verified.

The difficulty that arises with the first problem is similar to the problem with computing averages for the bifaces that are a combination of both between-group differences and the frequency with which each

group is represented (as discussed in the previous section). Variability in the set of measurements made over the bifaces has two sources. One source is variability that arises even when there is but a single process that gives rise to the data in hand. Variability may be due to "errors" in the objects being produced through a single production process even when artisans attempt to produce the same value for the dimension in question. The other source of variation is due to differences in outcomes between different processes. The degree of variation in the data brought forward for analysis is a sum of these two effects; hence, it is unclear whether a principal component is measuring variability among objects that belong to the same underlying type or the relative frequency with which the underlying types are represented in the data brought forward for analysis.

The principal component derived by Wynn and Tierney, if it is to be interpretable with respect to the amount of shape variability that occurs within a single type of bifaces, must be based on variation over the members of a single type of biface and not variation in a data set that is a mixture of several types of bifaces. In brief, the method of principal components is a way to reduce variable redundancy over a homogeneous set of objects, not over a heterogeneous set of objects. But the task at hand is to determine precisely those homogeneous sets of artifacts making up the data set brought forward for analysis. The means for so doing cannot be based on methods that assume, incorrectly, the problem of dividing a heterogeneous data set into homogeneous data sets has already been accomplished.

Digitization and Mathematical Representation of an Outline

While the archival property can be achieved by increasing the density of the digitized points on an outline, the cost in so doing lies in the increased number of variables when we consider each digitized point to be the value of a variable defined just for the part of the object represented by that digitized point. Rather than introducing a variable for each digitized point, we need a method for converting the digitization directly into a mathematical representation of the digitized boundary. In some cases, the representation may be done through characterizing the boundary with a mathematical expression such as a simple equation. The parameters in the mathematical expression can then be used as a set of measures that satisfy the archival property. The mathematical expression also serves as the rule for drawing the curved segment from the parameter values.

The main difficulty in implementing this method for representing a boundary lies in identifying the appropriate mathematical expression.

For simple geometric outlines, the representation can be straightforward. A circle can be represented in a Cartesian coordinate system by the expression $(x-a)^2 + (y-b)^2 = r^2$, where (a, b) is the location of the center of the circle in the Cartesian coordinate system. In a polar coordinate system, the circle may be represented by $r(\theta) = r, 0 \leq \theta \leq 2\pi$. In both cases, the parameter r is a single measurement that represents the radius of a circle.

Other simple mathematical expressions are (all in a Cartesian coordinate system) (1) $y = a + bx$ (straight line); (2) $y = a + bx + cx^2$ (quadratic, which varies from a parabola to a hyperbola, depending on the sign of the parameters a, b, and c); (3) $y = ae^{bx}$ (exponential curve); and (4) $y = ax^n$ (power law curve). While the parameter r for a circle can be measured directly from a circular outline, the parameters for other mathematical expressions cannot be measured as easily from an outline. Instead, the parameters can be computed from a digitized representation of the outline using statistical curve fitting methods. For a smooth curve, parameter estimation using statistical curve fitting methods will be quite accurate and constructing confidence intervals for parameter estimates will not be needed; the size of the confidence interval is likely to be on a par with, or smaller, than, measurement error introduced through digitization.

The method of fitting a mathematical expression to a boundary assumes that one knows the appropriate mathematical expression. Even a segment of the outline of an artifact, though, need not have a simple mathematical representation (even when smoothed to eliminate variation that represents the idiosyncrasies of artifact production). In some instances, the mathematical expression for the curvature of a segment may be determined from constraints acting on the process underlying the production of the curved segment—such as distribution of forces acting on the formation of the boundary of an artifact, as occurs with the hands of the potter making pottery with a pottery wheel—but in most cases the underlying physics may be too complex to model or there is no single force pattern that constrains the boundary. For lithics such as projectile points, the shape of the boundary is due at a fine level to the physics of the knapping technique and at a coarse level to the artisan's degree of control over the boundary as he or she produces a lithic object. What we need, then, is a procedure that can construct a mathematical representation of the boundary or a boundary segment to whatever degree of accuracy is desired.

There are two primary mathematical methods for constructing a mathematical expression that represents a curve as accurately as desired. Both are based on the idea of forming a sum of terms, where each additional term in the sum introduces increasingly fine changes in the form

of the curve into the mathematical expression. One method is based on a Cartesian coordinate system and the other on a polar coordinate system.

The method based on a Cartesian coordinate system uses the fact that, for most reasonable curves, a curve can be represented in the form of a power series. A *power series* is a mathematical expression of the form $y = a_0 + a_1x + a_2x^2 + \ldots = \sum_{i=0}^{i=\infty} a_i x^i$, $0 \le i < \infty$. The equation of a straight line, $y = a + bx$, has the form of a power series where $a_0 = a$, $a_1 = b$ and $a_i = 0$, $2 \le i < \infty$. Similarly, the quadratic expression $y = a + bx + cx^2$ is in the form of a power series where $a_0 = a$, $a_1 = b$, $a_2 = c$ and $a_i = 0$, $3 \le i < \infty$. A power series can be made to fit any reasonable curve with whatever degree of accuracy is desired by suitable choice of values for the parameters a_i, $0 \le i < \infty$.

Though a power series will provide a mathematical expression for virtually any curve that can be interpreted as representing a mathematical function, one limitation of this method for representing a curve lies in the requirement that (a) the curve be placed in a rectangular coordinate system in such a manner that a line vertical to the x-axis will intersect the curve at most once and (b) the curves to be compared to each other have a comparable way for orienting them in the coordinate system. A closed curve such as the boundary of a projectile point clearly contradicts the first requirement. However, if the outline is divided into segments based on the corners of the projectile point outline, each segment can be oriented with its own coordinate system so that it satisfies the "only one intersection" criterion. This requires that the orientation of the coordinate systems to each other be specified (see Read and Lestrel 1986).

The requirement for a comparable way to orient different curves in a coordinate system arises from the fact that if the orientation of the curve is changed, then the parameters will assume different values even though there is no change in the form of the curve. Differences in parameter values between two curves may thus be due either to differences in the curves or the orientation of the curves in the coordinate system, or a combination of the two. In effect, one needs a "natural" orientation of the curves with respect to the coordinate system, and whether there is a "natural" orientation depends on how the artifact was conceptualized and produced. If the artifact was perceived as having an axis (as is likely in the case of artifacts with symmetric outlines), then that axis can become one of the axes of the coordinate system and the other, perpendicular axis for the coordinate system can be located at a point along the boundary that is comparably defined across the artifacts that are to be compared—that is, a homologous point. The tip of a projectile point would be an example of a homologous point for projectile points.

If, however, the production process is one in which there is no overall orientation, but as the production proceeds the shape responds to local attributes in the sense of a design whose next feature is based on the portion of the design already produced, then there is no natural orientation. An example would be the edge of an Olduwan chopper in which flakes are removed to make a working edge, where each subsequent flake removal is "guided" by the previous flake removal and not by a "preset" design for the working edge. Or if an artifact is made up of distinct parts that each have their own design, and the overall design primarily expresses the relationships of the parts to each other rather than a single overarching design for the artifact as a whole, then each part would have its own coordinate system and the object as a whole would be expressed through the relationships among the coordinate systems (e.g., relative location of the origin for each coordinate system and the angular relationship of axes between the coordinate systems).

When it is the shape as a whole that needs to be represented, and particularly for a shape whose outline is a closed curve, the requirement for a rectangular coordinate system for which a vertical line can intersect the curve at most once can be resolved by using either a Fourier series or an elliptical Fourier series representation for a curve based on a polar coordinate system instead of a power series representation. Fourier series have been applied to archaeological data by Gero and Mazzullo (1984) in their study of the outlines of flake tools from the site of Huarticco in Peru.

A Fourier series is similar to a power series in that it is a sum of mathematical terms, except that trigonometric functions—sine and cosine—rather than power functions are used for the terms in the series. The simplest example of a Fourier series is an expression of the form $r(\theta) = r_0 + \sum_{n=1}^{n=\infty} r_n \cos(n\theta - \theta_n)$. The parameter r_n is referred to as the amplitude of the term in which it appears. The representation of the artifact outline is given by the parameters r_n and θ_n, $1 \le n < \infty$, in combination with the mathematical expression for the Fourier series.

Trigonometric functions are used for the Fourier series representation, since when one traces around a closed curved in polar coordinates, the function represented by the curve—that is, the set of points $(\theta, r(\theta))$ along the closed curve—is periodic with period 2π radians (= 360 degrees) and the trigonometric functions are periodic with period 2π. Like the power series representation with its requirement that a vertical line can only intersect the curve drawn in Cartesian coordinates at most once, the Fourier representation requires that a ray from the origin of the polar coordinate system can only intersect the curve once (a condition that may easily be violated with complex boundaries). A wide variety

of closed curves can be drawn in polar coordinates without violating the "intersect at most one time" requirement. Even the intersection requirement can be dropped with the use of an elliptical Fourier series representation of a curve (Kuhl and Giardina 1982; Lestrel 1997). The latter can represent virtually any curve—even those that cross themselves, as might occur with the tracing of a design that is part of the decoration of an artifact—and elliptical Fourier series can represent open curves simply by retracing the curve in the opposite direction so as to make a closed curve that does not encompass any area.

As discussed by Gero and Mazzullo (1984) in their application of Fourier series to the outlines of flake tools from the site of Huarticco in Peru, the power of the Fourier (and the more general elliptical Fourier series) representation of a curve lies in the ability to represent even irregular curves simply by including a sufficient number of terms with nonzero coefficients in the Fourier series. Like the power series representation, the Fourier representation begins with a digitization of the outline (which may be done in rectangular coordinates and then converted to polar coordinates) and uses a standard algorithm found in most statistical packages to fit a Fourier series with the desired degree of accuracy to the outline that has been traced. Gero and Mazzullo found that the angularity of the outline was consistently greater in the retouched flake tools than in the utilized flakes, based on a pattern of consistently larger amplitude values for the retouched tools in comparison to the retouched flakes.

Both the power series and the Fourier series representation for curves satisfy the archival property. The Fourier series representation has the virtue of being able to represent complete outlines, especially closed outlines, with greater facility than the power series representation. Achieving the archival property comes at a cost, however, in terms of redundancy. Both series may need a large number of terms in order to accurately represent an outline, but many of the terms are introduced solely for mathematical reasons relating to approximating a non-smoothly changing curve. For example, corners are difficult to approximate with the waveform represented by sine and cosine functions; hence, a large number of terms are needed to force the curve represented by the Fourier series to represent a corner. A large number of terms, and hence a large number of variables since there will be one variable for each parameter that appears in a series, does not imply an equally large number of dimensions from the viewpoint of cultural saliency.

We need ways to construct the relevant dimensions from the parameters determined by the power series or by the Fourier series, but there are no a priori mathematical methods for so doing. While the amplitude values in the Fourier representation provide a good "signature" for a particular curve, we need more than a signature for purposes of classification: we need to be able to relate variation in the signature to aspects of the morphological shape that had direct relevance to the artisan. But there is no clear relationship between the amplitude values in the Fourier representation and specific aspects of the outline. From the perspective of attributes versus modes, the variables generated by digitization of a curve are not modes since there is no reason to assume that the artisans who made the bifaces were guided by the conceptual equivalent of a polar or Cartesian coordinate system.

One aspect of the curve that can be directly measured through the Fourier or power series representation is the degree of curvature and change in the degree of curvature of a curve. For a simple geometric form such as a circle, the radius of the circle measures the degree of curvature and there is no change in the degree of curvature as one traverses the perimeter of the circle. For more complicated curves, the degree of curvature at a point on the curve can be defined in terms of the radius of the circle that best matches the curvature of the curve at that point. If the radius of the circle best fitting the actual curve is computed for each point along the curve, then we can use a graph of the radii so determined versus arc length from a fixed starting point on the curve as a visual representation of the change in the curvature of the curve as one traverses the curve (Main 1978). For a circle, the graph will be a horizontal line representing the fixed radius valued computed for each point along the perimeter of the circle.

When the curve has a mathematical representation such as a power series or an elliptical Fourier series, the curvature can be computed directly from the mathematical representation and the measure of curvature can be provided in the form of an equation whose graph will give a visual impression of the change in the curvature of the artifact. Increasing the number of terms in the representation, though it adds redundancy from the viewpoint of representing the curve directly, makes the graph of the curvature of the curve more accurate and less problematic. Rather than approximating curvature by taking the ratios of a series of width measurements as has been done with the bifaces discussed above, the digitized outline can be converted into an elliptical Fourier representation of the artifact outline and the Fourier representation can then be used to compute a mathematical expression giving the change in curvature of the outline as one traverses around the outline of the artifact.

Direct Measurement of an Outline

An alternative to measuring shape through digitization is to construct a series of measures that relate to important aspects of the overall shape. The measures may be distance measures such as the width of an object

(distance from one side to the other side), angular measures (angle of the tip of a projectile point), or radial measures (radius of curvature of the side of an artifact). Measures of this sort are better candidates for constructing dimensions than those based on points along the outline of an artifact. Ratios can be constructed to obtain shape measures and the measures can be tailored to focus on the parts that make up the overall shape of an artifact. The latter brings in to play—at least indirectly—the notion that the artifact as a whole may best be considered as a series of parts joined together, such as a projectile point composed of a base, body, and tip of the projectile point.

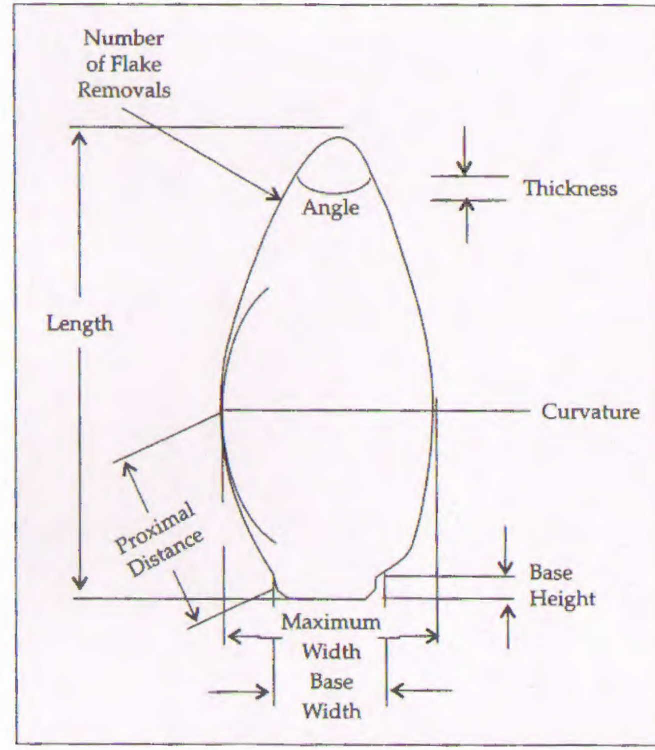
Here we will consider two approaches to measurement systems of this kind. The first is not concerned with the archival property as a goal. The second takes into account the archival property directly and provides a measurement system that focuses on direct representation of aspects of the shape of the artifact, while simultaneously satisfying the archival property.

Nonarchival, Nonredundant Shape Measures

Several systems have been proposed (e.g., Suhm et al. 1954; Ford and Webb 1956; Kneberg 1956; Binford 1963; Benfer 1967; Luchterhand 1970; Thomas 1970, 1981; Gunn and Prewitt 1975; Kay 1975) for measuring lithics. Yet other researchers have devised (unpublished) measurement systems simply as part of their analysis of artifact materials. These measurement systems tend to be specific to the type of artifact being analyzed and focus on the aspects of the artifact that are deemed by the researcher to be significant. Generally, the attempt is to be exhaustive, though not in an archival sense. One example of this kind of measurement system for projectile points will be presented here, since it is the basis for a data set on projectile points that will be discussed in Chapter 8.

The projectile points in question were excavated from a prehistoric Indian site in Ventura, California (4VEN39) using a probability sample based on a grid-based random sampling of the surface area of the site. A variety of measurements were made on each projectile point (see Figure 6.5). From top to bottom the measurements are length (millimeters), angle of tip (nearest 5 degrees), curvature of the side (radius of best fitting circle), maximum width (millimeters), distance between location of maximum width to the proximal limits of the base (millimeters), base height (millimeters, positive if the base is concave and negative if the base is convex), base width (millimeters) and thickness (millimeters). In addition, the number of flake removals provided a proxy measure for the relative amount of effort that went into making a projectile point, based on the assumption that finer flaking represents more careful workmanship.

Figure 6.5: An almost archival measurement system for leaf shape projectile points



As can be seen from Figure 6.5, the set of measures is close to being an archival set of measures. The curvature of the edge of the projectile point is the main exception. The curvature was assumed to be that of a circle and the location of the maximum curvature along the edge of the point was not measured. Hence, the side profile of the projectile point is not archived in this set of measures. The set of measures is tailored to projectile points with this general shape and thereby would necessarily lead to a taxonomic (rather than a paradigmatic) typology for a data set should the data set include projectile points that are not well measured by this set of measures.

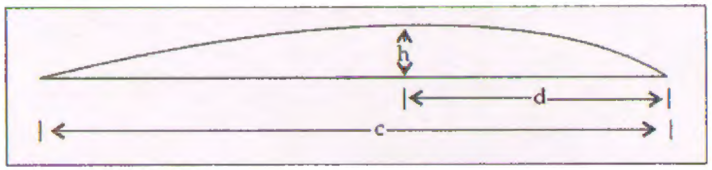
Archival and Nonredundant Shape Measures

Next we consider a measurement system for two-dimensional, simple outlines that satisfies both the archival and nonredundancy criteria. By a simple outline will be meant an outline that can be decomposed into a sequence of nonintersecting, connected C- or S-shaped curved line

segments. Qualitative shapes made up of a series of connected, curved segments (i.e. edges) can then be reconstructed from a representation of the edges and the angles through which edges are joined together to make a corner. We can consider the outline of many artifacts as being constructed in this manner; hence, the characterization of the outline of an artifact can be reduced to characterizing a series of curved line segments.

The underlying idea for the representation will be to construct a non-redundant measurement system for each of the curved segments and to specify how the curved segments are connected to form the outline. To do the first step, we will assume that a C curve can be adequately represented by three measurements: the length of a chord drawn from one end of the segment to the other end; the maximum height of the curve above this chord; and the distance from one end of the line segment to the point of maximum height above the chord (see Figure 6.6). It is clear that these three measurements are a minimal set for characterizing curves when we do not restrict ourselves to any single family of curves such as arc segments of a circle.

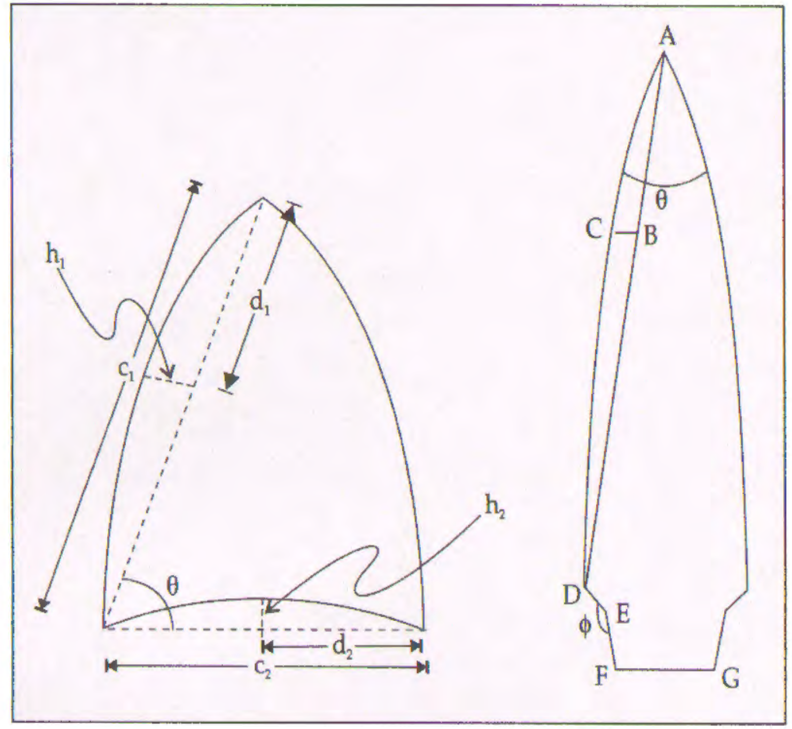
Figure 6.6: Quantitative representation of a curved line segment using three measures: chord length *c*; maximum height above the chord *h*; and distance to maximum height *d*



Although these three measurements do not completely characterize a C curve, the deviation of a redrawn C curve segment based on the three measures will be small for curves that smoothly fit the three points and substantial deviation will occur only for curves that are unlikely to occur in practice for the outlines of artifacts.[6] Hence, we will use an ordered triplet (c, h, d) to characterize a single curved C segment, where c is the chord length, h is the height above chord, and d is the distance to maximum height.

For outlines formed from several line segments, we can list the triplet for each segment, as well as the angle formed by the two chords that meet at a common corner when two curved segments are joined together (see Figure 6.7). When symmetry is an aspect of the complete curve, we need only list measurements for half the curve. Note that because we are presuming shape arises from the instantiation of cultural concepts about form and design, and so the actual artifact is only an imperfect

Figure 6.7: Left: representation of a more complex (symmetrical) shape by two ordered triplets, (c_1, h_1, d_1) and (c_2, h_2, d_2), and one angle, θ. These triplets and angle may be represented as a vector of dimension 7 = $(c_1, h_1, d_1, c_2, h_2, d_2, \theta)$. Right: representation for the outline of a Scottsbluff point



representation of those concepts, there may be ambiguity in decomposing an outline into a sequence of curves connected by corners. Actual artifacts have uneven rather than smooth outlines, "fuzzy" corners, and so on as a consequence of the material properties of the artifact, the care with which an artifact is made, use wear, and the like.

The assumption of an outline being composed of C curves joined at corners is inappropriate for pottery outlines since the outline of a jar may be based on S curves or even more complex curvature patterns. We can represent an S curve as two C curves (one in a convex direction and the other in a concave direction) that are joined smoothly with the connection point forming an inflection point (rather than a corner) for the S curve. Since there is a unique way two C curves can be joined together using an inflection point, we can characterize the S curve using

the above characterization of a C curve for each of the two C curves making up the S curve.

Natural Shapes and Working Edges

By virtue of the properties of the raw material, pottery objects have a constructed shape whereas lithic materials vary from shapes that result from the reduction process, which starts with the form of the raw material—such as a flint nodule—and ends with the form of the artifact when it is put to use (Jelinek 1976). The latter may take advantage of the shapes and edges produced in the reduction process and convert a "flaking edge" into a "working edge" with little or no modification of the shape of the material beyond the shape produced as part of the flake removal sequence. Utilized flakes, in which someone has taken a flake and then used an edge without first modifying the flake, are an extreme example of artifacts having a "natural" shape. Less extreme examples would be flakes that are partially retouched, such as many end-scrapers and side scrapers where only a portion of the flake shape has been modified. Or for the case of burins, a chisel-like edge is introduced through a particular way of striking a protrusion on a flake, but the overall shape of the flake need not be modified.

In all these cases, characterization of the outline of the shape of the flake is of less importance for relating the artifact to an emically relevant classification than linking a simple geometric characterization of the flake to the way it may have been held or hafted and how force may be transmitted to the working edge (Decker 1976). As noted by Gould for groups in the Western Desert of Australia, "To these people, the primary aim is to perform a task . . . with little interest being shown in the shape of the tool—*except for the angle of the working edge relative to the particular task involved*" (Gould 1971: 154, emphasis added). For flakes held with the hand, the method of holding ranges from a "power grip" that holds the artifact against the palm with the fingers wrapped around it, to a "precision grip" with the object held between the thumb and forefingers, possibly with the index finger touching the upper edge of the flake so that downward pressure can be applied by the index finger. A power grip may lead to the choice of a blade-like flake, with the longer dimension of the flake held parallel to the palm of the hand, thereby making the shorter edge of the flake perpendicular to the major axis of the flake the primary working edge. The same blade-like flake held with a precision grip would most likely use the edge of the flake parallel to the major axis of the flake (Read and Russell 1996).

These examples suggest that it is the overall geometry of the flake that relates to its possible use, not its precise shape. Different perceptions by

the user about the type of action that can be done effectively with the flake will relate to the angle of the utilized edge with respect to the major axis of the flake. The length of the utilized edge may indicate whether the flake was used with a slicing action with moderate downward force—hence resulting in a relatively long utilized edge—or a shorter edge may relate to a substantial downward force as can occur with a power grip.[7] In the latter case, the utilized edge will approximately be at right angles to the major axis of the flake. In addition, the angle of the utilized edge may relate to the task at hand, such as the distinction by the Australian Aborigines of the Western Desert between *purpuna* (utilized flakes with edge angles in the 40–90 degree range) that were used for woodworking and *tijimari* (utilized flakes with edge angles in the 15–60 degree range) that were used as knives (Gould 1980). Similarly, the Duna men of Papua New Guinea distinguished among *aré kou* ("real" flakes), *aré kone* (haftable flakes), and *aré nguni* (not sharp flakes) according to the overall geometry and the edges of the flake tools (White et al. 1977). Finally, the curvature of the utilized edge may relate to the kind of task or amount of usage.

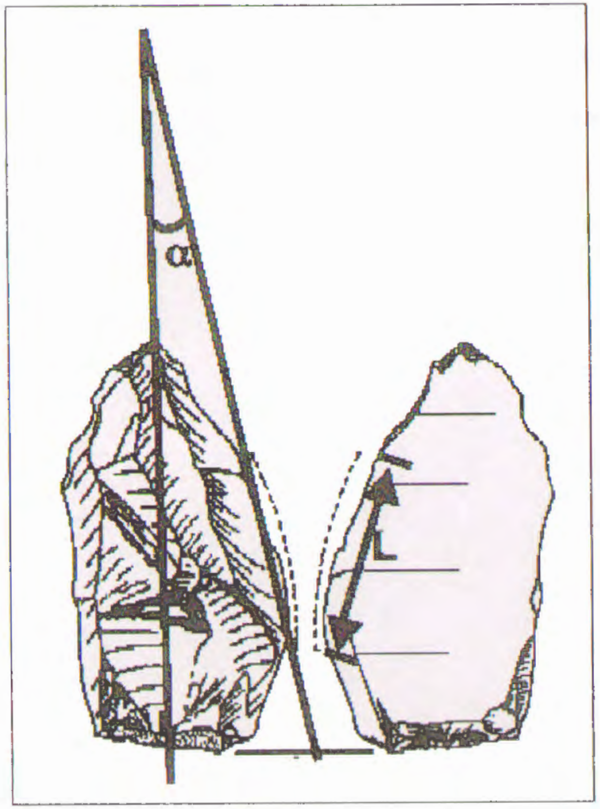
The metric measurement of tools with a "natural" shape (see Figure 6.8) highlights the difficulty of relating a measurement system to dimensions upon which a classification system will be constructed. The archival property and the redundancy constraint alone are not sufficient conditions for translating metric variables into culturally relevant dimensions. The shape measures used by Bordes and Roe assume that the width ratios express shape distinctions relevant to the makers and users of the bifaces. Though intuitive sorting of artifacts may lead to valid shape differences among the artifacts in the gestalt sense discussed by Adams and Adams (1991), any measurement system for these gestalt-perceived shape differences needs to be validated as an emically relevant measure of shape. Many of the differences posited in Bordes's typology do not adhere to this criterion. In addition, the archival property is not satisfied with his measurement system and emically relevant dimensions may not have been measured.

The problem of relating metric variables to emically relevant dimensions cannot be solved by using statistical methods unless one first shows that the assumptions of the statistical methods are consistent with the structuring process(es) for the data brought forward for analysis. This requires that we consider the relationship between artifacts and cultural concepts.

Conceptual Definition of an Artifact

If a typology is viewed primarily as a device for sorting artifacts, as suggested by Adams and Adams (1991), it follows that each artifact should be

Figure 6.8: Primary dimensions for a measurement system for utilized flakes



assignable to a type or category. This criterion can be satisfied technically by including the category "none of the above." For typologies constructed only for pragmatic reasons, pragmatic categories such as "none of the above" may be satisfactory. Nonetheless, the latter fails to address the relationship between categorization at the ideational level of how artifacts are conceptualized and the phenomenological level of the grouping of objects produced by artisans. There is no reason to assume that all objects made by artisans are related to culturally relevant categorizations; for example, some objects made be made for personal use, others may have been made to try out a new technique, yet others may have been made haphazardly, and so on.

For our purposes here, with the goal of devising a methodology for forming a typology whose types reflect the way in which artifacts are part of the cultural milieu of the artisans who produced and the persons who used them, we need to make more explicit the conceptual linkage

between artifacts as objects and artifacts as part of a conceptual system. The type/variety distinction addresses one aspect of the linkage through recognizing that the multifaceted nature of an artifact production process reflects not only constraints imposed by cultural concepts, but also effects due to artisan specific decisions during the production process.

Black and Weer's (1936) classification based on underlying geometric shapes, which takes into account shape transformations made by the artisan, identifies another aspect—the manner in which the conceptual domain is a structured domain of concepts and not simply a list of culturally determined categories or concepts. The transformation of a rectangle into what they referred to as a rectanguloid form, for example, must occur conceptually before it is realized on the object that is produced; as noted by Pelegrin, even for the production of symmetrical bifaces by *Homo erectus*, "[t]echnical actions . . . were subordinate to, and structured by, geometric intensions" (Pelegrin 2005: 30). The idea of a transformation suggests a dynamic aspect at the conceptual level that is lost when the conceptual level is reduced to a static construct such as a "mental template," defined as "the idea of the proper form of an object [which] exists in the mind of the maker" (Deetz 1967: 45). Something like a "mental template" might still be involved since the artisan does not go from unformed raw material to a common finished form reproduced repeatedly by different artisans unless there is a shared "mental template" of some sort that informs the artisan about that form (where "shared" need not mean "consciously shared"), for "it is inconceivable that patterned actions of technology—even those that seem ad hoc and responsive to immediate conditions—can proceed without some kind of 'plan' even if that plan is nothing more than a vocabulary of known alternatives" (Bleed 2001: 122). Nonetheless, the "mental template" metaphor is too stringent since it does not account for the range of artifacts that is also produced in a comparable manner from one artisan to the next, but where the form is primarily the consequence of the technology used to produce the object at hand—as is true for lithic objects that have an overall form or shape that is not constructed by the artisan.

Let us return to a fundamental question. Why do we consider an object to be an artifact? The simple answer is that an artifact is an object that has been formed or modified by humans. We use this kind of "rough and ready" definition in fieldwork when we teach students the difference between an atifact and something that simply looks like an artifact. When we had new students doing survey work in the Chevelon drainage in northern Arizona, a novice student would pick up something that had the shape of a pottery sherd and we would indicate what features distinguish a pottery sherd from a natural object. After a number of trials,

novice students began to see the difference between an object that clearly was manmade and a natural object that merely resembled a manmade object.

Though "artifacts are human modified objects" is a useful definition, and though it is a definition that works correctly in many cases, it is evident that it is neither a sufficient nor a necessary definition. It is not a sufficient definition for clearly we do not consider every object that has been modified by humans to be artifacts. For example, we do not consider the CO_2 that we breathe out to be an artifact even though it is our body that has provided the conditions under which oxygen breathed in combines with carbon to produce CO_2 as a bodily waste product. Similarly, we do not consider leaves crushed or twigs broken when walking through the woods to be artifacts even though they may indicate that a person has passed by. Equally, a piece of wood that someone has whittled on haphazardly to pass the time is not likely to be considered an artifact. While we might attempt to refine our definition by adding the stipulation "purposefully modified," we still have not resolved the problem of distinguishing when we consider an object to be an artifact. If I purposefully break a branch while walking by a tree and then throw it on the ground without any intent for my action to have meaning for others, it has not yet become an artifact.

This definition is also defective in terms of what it excludes. The definition assumes that an object is an artifact only when it is modified by human action. This would exclude a natural object that is used in precisely the same manner as a bona fide artifact from being considered an artifact. But as noted by Tindale, "Palungkwatji [his informant] on more than one occasion had no special hammerstone for knapping his flakes. Usually he improvised by picking up a small stone of suitable size" (Tindale 1985). Gould (1980) makes similar observations for aborigines of the Western Desert in Australia. If we insist on the "modified by humans" criterion, the unmodified stone is not an artifact, but this appears to put form over substance. It seems more reasonable to say that the stone used as a hammerstone is an artifact because it was *conceptualized* as being suitable to be a hammerstone, and in fact it was used as a hammerstone even though it was not modified prior to use.

Similarly, a human modified object can change from being one kind of artifact to another without modification simply according to how it is conceptualized. A coin that is used to turn a screw temporarily becomes a screwdriver. A credit card used to cut through soft food when a knife is not available temporarily takes on the status of a knife (Read 1982).

While human modification may frequently be a sufficient characterization for an object to be an artifact, it is insufficient (as these examples suggest) for distinguishing why one object is an artifact and another

is not. What makes the rock picked up and used as a hammerstone an artifact, and what transforms the coin and credit card from one kind of artifact to another, lies in the conceptualization that the actor has made of the object based on observing that the attributes necessary for the task at hand are present on the object even though the attributes may have been introduced for a different purpose or are even just happenstance. The stone becomes a hammerstone because Tindale's informant Palungkwatji perceives that a particular stone has the appropriate attributes, in its unmodified form, to be a hammerstone. The coin can be used in place of a screwdriver because it is perceived to have features that allow a rotary force to be applied to the coin and the coin, in turn, can transfer the force of that rotary motion to the screw. Let us define, then, an artifact in terms of conceptualization.

> Definition: *An artifact is a material object conceptualized by the members of a social group as belonging to a category that is part of the cultural repertoire for that group* (modified from Read 1982).

The key aspect of the definition lies in the idea that an object is an artifact by virtue of how it is conceptualized and not simply by the fact of it being modified by human agents; it is the "externalization of the *tool-idea*" (Gallus 1977: 135). The definition does not contradict the human modification notion of an artifact. Instead, it allows for a distinction to be made between modification that is relevant to an object being categorized and modification that occurs simply because of our interaction with the physical world. At the same time, it does not limit the notion of an artifact to modification. Nor does it require that it is the material functionality of an object that makes it an artifact, for objects may be conceptualized as belonging to a category for symbolic or other reasons. This interplay between conceptualization, production, and use has been made explicit in the *chaîne opératoire* approach to characterizing artifact production, categorization, and use—the topic of the next chapter.

7

Production and Categorization Sequences

Production Sequences

The conceptual definition of an artifact does not convey the dynamic aspect implied by the "rough and ready" definition of an artifact as a human-modified object. The latter asserts that artifacts are produced; hence, there is a sequence of steps in the production of an object/artifact by the artisan. In addition, subsequent changes to the object due to usage may lead to the object being discarded. Object production involves a technology that can change the form of an object. Usage also transforms an object but by a different means. This transformational view of artifacts going from raw material to discarded object has been given the term *chaîne opératoire* by French-language archaeologists (e.g., Boëda et al. 1990; Geneste 1991; Pigeot 1991; De Bie 1998; Honegger 2001) and has been discussed by a number of English-language researchers (e.g., Edmonds 1990; Dobres 1992; Schlanger 1994; Bar-Yosef and Kuhn 1999; Bleed 2001).

Although the *chaîne opératoire* approach has tended to emphasize lithic reduction sequences (Odell 2001), its broader aim is

> to describe and understand all *cultural transformations* that a specific raw material had to go through. It is a chronological segmentation of the actions and *mental processes* required in the manufacture of an artifact and in its maintenance into the technical system of a prehistoric group. The initial stage of the chain is raw material procurement, and the final stage is the discard of the artifact. (Sellet 1993: 106, emphasis added)

The inclusion of cultural and mental processes in the definition of the *chaîne opératoire* approach is evident in the conclusion reached by Pigeot (1991; see also van der Leeuw 2000) that the conceptual geometry required

for making stone tools increased in dimensionality during hominid evolution from zero dimensional points to one-dimensional edges (e.g., choppers), two-dimensional outlines (e.g., the shape of a hand axe), and finally manipulation of three-dimensional solids (e.g., blade technology). While all of the objects exist in three dimensions, Pigeot argued that conceptually the matter is more complex since the geometry relates to the conceptual aspect of the tool under the control of the artisan.

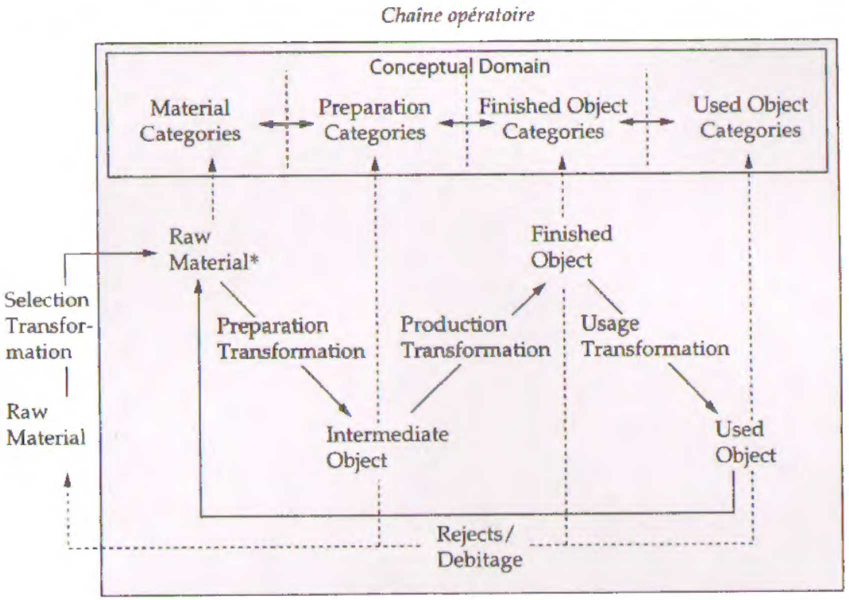
This emphasis on the conceptual processes involved in the production of artifacts distinguishes the *chaîne opératoire* approach from the otherwise similar transformational sequence discussed by Schiffer (2002 [1976]) and lithic reduction models (e.g., Collins 1975; Flenniken 1981; Magne 1985) that describe the steps involved in the production of a lithic artifact. The *chaîne opératoire* approach explicitly frames the process going from raw material to discarded artifact as one involving object transformation linked with mental processes brought to bear when carrying out the stages in a production sequence for object transformation (Julien and Julien 1994). These mental processes relate not only to the stages of object transformation, but can include categorizations of the objects in the various stages of the sequence as well as categorization of the finished object by the producers and users of those finished objects. Categorizing the finished object conceptually transforms the finished object into an artifact, as discussed in the previous chapter. We can diagram the production sequence and its connections with the conceptual domain as shown in Figure 7.1 (compare with Figure 3.2 for pottery production).

Transformation: Raw Material into Raw Material*

The beginning point of the *chaîne opératoire* production sequence is the conceptual transformation of raw material found in nature into what we will refer to as raw material* through selection and categorization (see the solid and dashed arrows from raw material to raw material* to Material Categories in the Conceptual Domain in Figure 7.1). At the phenomenological level, raw material is selected that has the potential for undergoing transformation into finished objects (Ellis and Lothrop 1989; Kooyman 2000: 49)—for example, the widespread use of cryptocrystalline siliceous rocks for lithics among North American Paleo-Indians (Ellis 1989; Goodyear 1989). Through selection and categorization, raw material becomes raw material*, an instance of the Material Categories concept of the artisans.

This process of bringing raw material into the conceptual domain of the artisan can be seen in the fact that indigenous Australian flint

Figure 7.1: *Chaîne opératoire* sequence for the production of lithic tools



knappers had a term for raw material suitable for transforming into a stone implement. This raw material "is known to the Djaru people as [tjamuru]" (Tindale 1985: 4; see also Hayden 1977); that is, the Djaru of Australia do not simply obtain raw material but categorize the raw material suitable for making lithic tools. For pottery, the comparable conceptual transformation of raw material into raw material* would include categorization of different sources or kinds of clay from which pots will be made. Similar categorization would apply to other raw material such as wood or bone.

Transformation: Raw Material* into a Blank

The next major step in the *chaîne opératoire* sequence is the transformation of raw material* into an intermediate form from which an artisan will produce the intended object. For lithics, this typically consists of a sequence of reduction steps and associated technology required to transform raw material* into a blank (Kooyman 2000: 49), with the latter defined as "an early stage in a chipped stone production sequence where the final form is not apparent" (Crabtree 1972: 42; see also Pavesic 1985: 68; Débenath and Dibble 1994). For the Australian flint knappers, the lithic blanks were termed *jambatji* when they were large and were "traded for finishing by others" (Tindale 1985), whereas smaller blanks were called

tjimbila, the term also used for the knives made from this kind of blank (Tindale 1985). Thus, this stage in the production sequence is culturally salient for the Djaru and is not just an etic stage in the reduction process that has been distinguished analytically. In pottery making, a comparable step would be the preparation of a lump of clay from which a pottery object will be formed.

Transformation: Blank into Finished Object

The next major step in the *chaîne opératoire* sequence involves the production of the finished object from the intermediate stage based on conceptualizations about material technology needed to carry out this sequence. Several subtasks may be involved, depending on the technology being used and the kind of raw material* being transformed. For lithics, a subtask may include the production of a preform defined as "a late stage of production without the refinements of the completed tool" (Crabtree 1972: 85; see also Pavesic 1985: 68).

Material may exit from the production sequence as discards through not having desired attributes (such as a flake that is too thin to make the intended spear point), material defects, errors in production, breakage, and the like (see dotted arrows, Figure 7.1). When the finished object can have little variation, the discard rate may be high; for example, Dietler (2003) reports a 90% rejection for making backed bladelets by the Chumash on Catalina Island off the coast of Santa Barbara. Or the breakage rate may be high during the production process, as appeared to be the case for the massive amounts of discarded material from two large lithic workshops at Colha, Belize, dating to 500–300 B.C. (Shafer 1985).

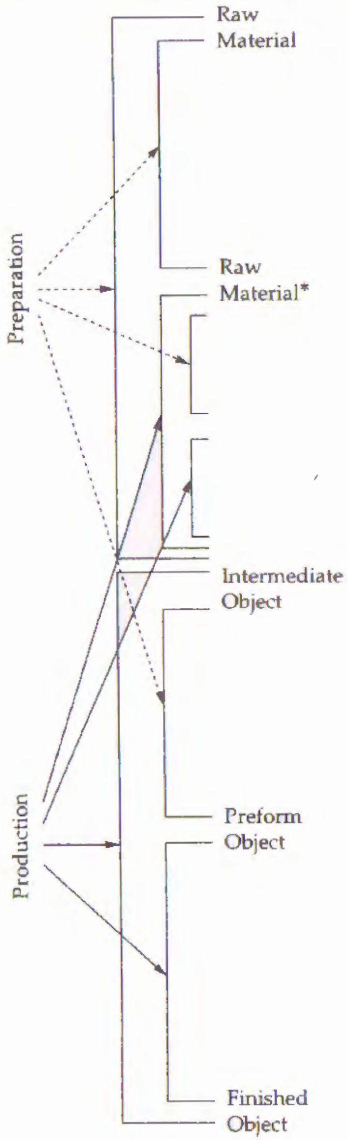
Finished objects used according to their intended (and sometimes unintended) purpose may become worn or broken and no longer satisfactory for the task at hand, whether the task be functional or symbolic. Usage wear or breakage transforms an artifact back into raw material* if the object is perceived to be capable of being resharpened or rejuvenated. Otherwise it may be discarded and thereby moves out of the conceptual system and reverts to raw material.

Technological Transformations and Recursion

Connecting the stages in the production sequence are technological transformations that take the output from a previous step and modify it using a technology that makes possible the production of the desired form of the object from the output of the earlier stage in the sequence. We can refer to implementation of the technology involved in going from raw material* to an intermediate stage—such as a blank in lithic

manufacture—as a *preparation transformation* since the output of this stage is a form suitable for being the beginning point in the next stage in the production sequence. A blank is a form from which a finished object will be produced. We can view the technology that transforms an intermediate stage into a finished object as a *production transformation* (see Figure 7.2).

Figure 7.2: Recursive preparation and production sequence



Each of these transformations can be subdivided recursively into two (sub)transformations that we can also call a preparation (sub)transformation and a production (sub)transformation; for example, a core (raw material*) is prepared (preparation (sub)transformation) by removing flakes to make a suitable striking platform for the removal of a flake (production (sub)transformation), which will then serve as an intermediate form. We can therefore view the production system from an abstract perspective as consisting of an embedded, recursive sequence of pairs of preparation/production stages (see Figure 7.2), similar to the embedding that occurs in language with sentences made up of embedded object/predicate pairs. The degree of embedding depends on the degree of specificity desired when modeling the production sequence—e.g., distinguishing among the different methods of flake removal that occur in lithic reduction sequences.

Categorization Sequence

Categorization and recategorization occurs in the *chaîne opératoire* sequence through several means. The transformation raw material → raw material* depends on determining that the raw material being considered has the attributes that are part of the definition of raw material*. From an analytical viewpoint, the categorization in this step is similar to the conceptual framework employed in numerical taxonomy whereby an object is assigned to a group—possibly using a polythetic definition—according to whether the object possesses the attributes in question (for nominal variables) or has a value within the range of values for metric variables that determine the category in question—in this case, the category, raw material*. From an analytical viewpoint, determining the attributes of the category raw material* for lithic objects is relatively straightforward since raw material* is composed of the actual raw material that has been used to produce objects whose emic categorization makes them artifacts; hence, the attributes of raw material* are a subset of the attributes of raw material.

Measurement

From a measurement perspective, identification of the kind(s) of raw material that are included in the category raw material* can be done through geological classification of the minerals and rocks (see, for example, Kooyman 2000: Chapter 3) from which lithics were produced, and for clays the raw material may be identified "by their physical, mineral, and trace-chemical properties" (Rice 1977: 225). Trace-chemical properties

may lead to a relatively large number of variables, not all of which reflect the characteristics relevant to the artisans. Since membership in the category raw material* may be inferred from the material used in the production of artifacts, the selection of variables that distinguish raw material* from other kinds of raw material may be done statistically using discriminant analysis (see discussion by Benfer and Benfer 1981).

The transformation from raw material* → blank is primarily a reduction transformation in the case of lithics and depends on the technology employed by the artisan with regard to tools used; preparation made of the raw material* to enable the reduction technology to be implemented; the particular methods by which the reduction takes place (e.g., core reduction versus retouching [Kuhn 1992]); and so on with other reduction procedures (Magne 1985; Odell 1989; Kooyman 2000). The technology involved in reduction sequences has been extensively studied, including characterization of the underlying sequence of production steps used by the artisan that can be analytically represented in the form of a production code or a production grammar (Young and Bonnichsen 1985).

The transformation from blank → finished object/artifact continues the reduction transformation in the case of lithics and identifies the sequence of steps and associated technology needed to give the object/artifact either its desired form or the desired form for a portion of the blank, such as forming a burin by removal of a burin sprawl or using retouch to modify the working edge of an artifact. The sequence of steps involved in this transformation continue the reduction steps involved in the previous step, though a different technology may be involved (e.g., core reduction versus pressure flaking) and the production code can be extended to include the steps going from blank to finished object. From a measurement viewpoint, the production code expresses a posited sequence of steps that would lead to the finished object that takes into account not only the final morphology, but possibly the scar pattern of flake removal according to the particular method of flake removal that was employed. Fluted projectile points, for example, are distinguished not only by their overall shape but also by a characteristic "fluting" due to the longitudinal removal of a flake, beginning at the base of the point and extending—in some cases—virtually the length of the point (e.g., Young and Bonnichsen 1985: Figure 4.5, Moosehorn fluted points). Measurement that focuses only on the outline of the point would not include information on the fluting that gives the projectile points their characteristic surface morphology.

The transformation from finished object/artifact → worn out object depends on the usage pattern for the tool and includes evaluation of any changes in the tool through wear and tear from usage that precludes categorization of the object as an artifact; that is, the changes in the object

that do not permit it to continue to meet the attributes of the category into which the finished object was embedded. The worn object has not lost its initial categorization but has become a transformed object that can no longer be used in the manner associated with the categorization of the object prior to wear. A dull knife blade is still a knife blade, but one that cannot perform satisfactorily the actions expected of a knife blade (such as cutting); a broken talisman may still have the material characteristics of a talisman, but it may no longer be perceived as being effective for providing protection. The "worn object" category represents a point in a sequence of actions where a decision needs to be made by the user whether to categorize the object as raw material* and hence subject it to rejuvenation, resharpening, or other kind of modification that leads again to a finished object (Hayden 1989). The alternative is to discard the worn object and thereby remove it from the conceptual system and make it part of the domain of raw material.

Categorization: Object Plus Stage

For the purposes of classification, the *chaîne opératoire* approach provides a way to unpack the dispute (Flenniken and Raymond 1986; Thomas 1986; Flenniken and Wilke 1989; Bettinger et al. 1991; Kuhn 1992; Grimaldi and Lemorini 1993; Dibble 1995; Rondeau 1996; Zeaneh and Elston 2001) over the impact of resharpening and rejuvenation on classification systems and typologies. When a type is defined simply on the basis of a group of objects that satisfy the internal cohesion/external isolation criterion for a cluster in n-dimensional space, the same general kinds of objects can be classified as if they are different kinds of objects, such as an unbroken versus a broken and resharpened projectile point.

In contrast, from the *chaîne opératoire* perspective, an object is categorized in accordance with the stage to which it belongs; that is, what is categorized is the object plus the stage in the sequence that it represents (see top of Figure 7.1). A (natural) object that begins as raw material is classified as raw material*, thereby making the object a candidate for modification leading to a finished object. After the object = raw material* is transformed through an initial reduction sequence, the resulting object may be classified as a blank and within the blank category as a kind of blank, as noted above for the Djaru. When the object = blank is modified and becomes a finished object, the object = finished object now becomes an artifact that is part of the categorization, finished objects. Through usage the object = artifact may be broken and then rejuvenated, and the rejuvenated object = worn artifact again becomes a finished object and categorized again as an artifact. Thus, the sequence

going from raw material and eventually back to raw material allows for multiple classifications of the same material object as it undergoes various transformations.

The classification of objects at intermediate stages in the sequence differs in meaning from classification of finished objects. The intermediate steps identified in Figure 7.1 need not be culture specific since they represent steps in a production sequence that is likely to be common in a wide variety of cultural contexts. Artisans universally distinguish among all possible raw material available to them as to what constitutes raw material* for the task at hand, and similar choices may be made regardless of cultural context. The task at hand acts as a filter for what raw material will be introduced into the *chaîne opératoire* sequence through having properties that are amenable to the technology used in the production of a finished object and the intended use of the object.

Technologies are widely shared across different social groupings, through both diffusion and convergence; hence, the raw material categorized as raw material* will tend to overlap in content across cultural groupings, as well as in terms of being a categorization of raw material suitable for the task at hand. Similarly, to the extent that the production sequence going from raw material* to finished object has an in-between stage (or stages) distinguished by artisans as a stage in the production sequence, then an in-between stage may be categorized in the *chaîne opératoire* sequence as a blank; and to the extent that the category, blank, simply represents an intermediate stage in the production sequence, it need not be culture specific (though the form of the blank may be culture specific). When a category such as "blank" represents a stage in a production sequence, measurement is likely to be reduced to a few dimensions that distinguish among blanks since specific features of the blank—such as its precise shape—may subsequently be modified in different ways to arrive at different finished objects and/or the shape may not be under tight control by the artisan, as when a blank is simply a flake produced via flake removal during transformation from raw material*.

Categorization and Material Properties

In the production sequence going from raw material to finished objects, categorization tends to go from categories whose criteria for membership arise from the nature of the material in question to distinctions that are imposed on that material through deliberate modification. The categorizations involved in raw material* tend to reflect choices made among physical differences in raw material that relate to intentional modification of the form or other characteristics. In contrast, finished objects reflect the distinctions that are part of the conceptual system of categories in which the finished object is embedded and the transformations that have been made in the production sequence are the means to imbue the finished object with attributes reflecting these distinctions. Although this is most evident with pottery, where the form of the raw material—clay—only constrains the final shape and form of the pot through broad limits (such as overall size and feasible wall thickness of the clay), it also occurs with lithics whose final form has been produced by the artisan.

In general, lithics differ from pottery by having intermediate stages whose morphological characteristics are only partially controlled by the artisan and whose morphological characteristics may already satisfy the criteria used for the characterization of an object as an artifact. The most extreme example of this difference is an unmodified flake selected for use in some task where the shape and edges of the flake already allow it to be used in a task without further modification. Intermediate stages would be the wide range of retouched lithics (such as scrapers) for which only a portion of the lithic object has been deliberately modified.

Measurement and the Artisan's Direct Control

Relevant measurements on objects that reflect those aspects of an object that are under the artisan's direct control vary from few or no dimensions at the level of raw material* to dimensions that characterize the form of the finished object in the case of pottery and bifacial lithics. The artisan only indirectly controls the characteristics of raw material* through selection of material that both has the characteristics deemed necessary for the finished object and is suitable for the technology used to produce the finished object. Some control over those properties can be exercised, such as heat treating of flint and firing of clay, but for the most part the process is one of selection rather than imposition. Intermediate stages are more mixed in that a stage such as a blank is the consequence of a preparation stage; hence, the attributes of interest in the blank reflect both the properties of the material (e.g., can the lithic blank hold up under the stresses imposed by further reduction of the object?) and the eventual morphological characteristics of the finished object. For example, as discussed by Geneste (1991) with regard to variation in production sequences for Middle and Upper Paleolithic sites in France, blanks can sometimes be specific to the finished object in a 1–1 manner or sometimes in a 1-many manner when the same kind of blank can be used to make a variety of finished objects.

As one goes from raw material* to a finished object, categorizations that are relevant at an earlier stage may or may not be relevant for distinctions made at a later stage. The kind of material is critical for categorizing raw material as raw material*, for example, but the kind of material may only relate to the technology used for object production and not to distinctions made among objects produced with that technology. The interdependence among the categorizations relevant to each of the stages in the *chaîne opératoire* sequence is indicated in Figure 7.1 by the double-headed arrows between the divisions in the conceptual domain.

We now have in place the conceptual foundation needed for constructing culturally salient artifact classifications. The next chapter develops the methods we can use to determine artifact types and their interconnections displayed through a typology.

8

Quantitative Classification: Methodology

The Double Bind Problem

For purposes of identifying types of artifacts, quantitative dimensions require different (Shott 2003) and more complex analytical methods than qualitative and bifurcated dimensions. The complexity stems from the combination of (1) not all the possible quantitative dimensions of an artifact are culturally salient and (2) even for a culturally salient dimension, there will be variation arising from the fact that the value for a dimension need not be mapped in an identical manner onto each artifact. For quantitative dimensions, patterning relevant to type definitions is therefore based on "patterning in the aggregate" and takes into account all the values measured over a collection of comparable objects. But what constitutes comparable objects is not immediately self-evident and can lead to a double bind when using quantitative dimensions to identify artifact types—hence, the increased analytical complexity.

The double bind arises as follows. To determine culturally salient artifact types, we need to compare an individual artifact to other artifacts of the same type, yet we do not know what constitutes other artifacts of the same type until we have determined the culturally salient artifact types. This problem of mutual interdependence does not arise equally with qualitative dimensions since qualitative measures such as type of material, surface treatment, and decorated or not decorated are observable on individual artifacts and represent decision making on the part of the artisan. Similarly, bifurcated dimensions such as sand temper versus sherd temper in American Southwest pottery are culturally salient when different artisans used the same bifurcation across wide regions and over relatively long time periods.

The double bind of needing in advance the types required to carry out the analysis that is supposed to identify those types poses analytical circularities that might lead us to reject the use of quantitative measurements

for identifying artifact types. However, despite the analytical problems that arise when using quantitative measurements to identify types of artifacts, quantitative measurements are necessary; there are culturally salient dimensions of artifacts that are neither qualitative nor dimensions bifurcated by the makers of artifacts. A variable that measures a culturally salient aspect of the morphological form of an artifact, for example, is likely to lead to a quantitative measurement since morphological dimensions are difficult to bifurcate and there is usually not enough control over the outcome of the production process to be able to change a continuous into a bifurcated dimension.

Even if artisans have two distinct lengths in mind for projectile points, those lengths cannot be produced precisely and instead the lengths of projectile points produced by the artisan will have a range of values centered on the intended length. Analytically, we can measure the length of a projectile point that was produced by the artisan; but from the viewpoint of forming a typology of projectile points, we need to consider the pattern for the length values measured over a collection of projectile points to determine if there was an intended mean length value—and if so, to use the intended value as the basis for defining a projectile point type using culturally salient distinctions in the lengths of the projectile points.

This chapter develops methods for resolving the double bind to determine if quantitative measurements made over individual artifacts relate to an underlying, intended value that, in turn, will be used as part of a type definition. The means for resolving the double bind will be based on how the individual value obtained on a single artifact relates to the expected pattern of values obtained for a group of artifacts when the latter was produced using a culturally salient dimension. This approach leads us to statistical methods since the underlying goal of statistical analysis is to delineate patterning that can only be observed in the aggregate. Our analytical task will go beyond statistical analysis, however; statistical methods do not directly address the double bind of relating an individual artifact to other, comparable artifacts when the group of artifacts is not known in advance, and where the comparable artifacts are to be determined through the analysis of quantitative dimensions.

Statistical Patterning in the Aggregate

Statistical Population

The notion of an aggregate over which patterning is to be discerned is made more precise in statistical analysis through the concept of what we can call an empirical population. An *empirical population* is a well-defined collection of actual entities over which quantitative measurements will be made for one or more variables deemed relevant to the properties of interest and appropriate for analyzing the entities brought forward for study. By well-defined is meant whether one has a membership rule for the population that makes it evident if an entity belongs to that population. Thus the population "all pottery material recovered in an archaeological site through excavation by the archaeologist" is well-defined, since for any object it is presumably known whether it is pottery material recovered by the archaeologist. Though well-defined, the population is not necessarily of primary archaeological interest: we are concerned not only with what was excavated but also, more broadly, with all the artifacts produced by the inhabitants of the settlement (or settlements) that gave rise to the archaeological site. Hence, the boundary for the statistical population has been drawn too narrowly and should be broadened to give the population greater archaeological interest.

The distinction between a well-defined population and a population of archaeological interest underscores an interpretive problem that arises with the "well-defined" aspect of a population definition. As we try to expand the boundary of a population to make it more meaningful for archaeological purposes, we also tend to make the population less well defined. We can expand the population defined above into an archaeologically more meaningful population by broadening the definition to include "all of the pottery artifacts produced by the inhabitants of the settlement represented by the archaeological site excavated by the archaeologist." Though this more broadly defined population appears at first glance to be well-defined, it has three defects. First, the time period in question is not specified; second, there may be disagreement among those who lived in the settlement as to who is—or is not—an inhabitant of a settlement; and third, there is lack of specification as to the spatial locality where the pottery was made. Is a pottery object made by an inhabitant of one settlement while temporarily living in a different settlement part of the population of pottery objects?

These defects in the population definition can be remedied by adding qualifications such as the time period in question and whether the pottery object must have been made by a resident artisan—but only at the cost of generality. A more specific time period may exclude data of interest; pottery made by a nonresident artisan may provide information on the interaction among different settlements; and so on.

Though what constitutes both a well-defined empirical population and an archaeologically meaningful empirical population is central to the appropriate application of statistical methods to archaeological data, we will not pursue the problem of forming a meaningful, well-defined

empirical population of *actual* artifacts in more detail here. We will eventually use a definition of a population based not only on what was produced over a particular time period and at a specific location, but also on what could have been produced keeping fixed the conceptual and technological system(s) used in the production of the artifacts in question.

Assume for the moment that we have formulated a satisfactory definition of an empirical population of actual artifacts and we have decided upon the variable(s) that will be measured over the members of the population (or at least over a sample of entities obtained from the population). Our initial task is to uncover patterning embedded in the measurements made over the objects in this population. For illustrative purposes, let us define our population to be, say, the collection of projectile points excavated from the Ventura County (California) Paleo-Indian site called 4VEN39.[1] We will initially consider a single variable and then expand upon the analysis done with a single variable to include the multivariate case. The initial variable V will be the angle of the tip of the projectile point, measured to the nearest five degrees.

Tabular Representation of Pattern: A Frequency Distribution Table

A frequency distribution table lists the values of the variable that occurred over the population being analyzed; the frequency n, with which each value occurred in the population; and the proportion p of the population made up of each value. The frequency distribution table (see Table 8.1)

Table 8.1: Projectile Points from 4VEN39, Ventura, California

Angle of Point Tip, V	Frequency, n	Proportion, p
15	1	0.02
20	6	0.09
25	3	0.05
30	6	0.09
35	8	0.13
40	13	0.20
45	10	0.16
50	8	0.13
55	3	0.05
60	5	0.08
65	0	0.00
70	0	0.00
75	1	0.02

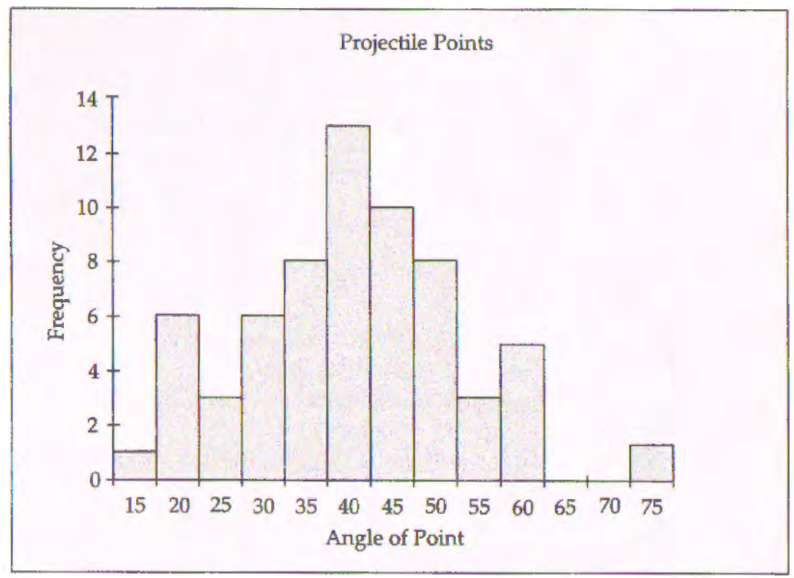
Total $N = 64$

for the angle variable V lists the values that either occurred when we measured the value of V over the members of the population of entities or are within the range for those values. It is evident from the table that angles in the 35–50 degree range are the more common values and the angle of 40 degrees is the most common angle in this population of projectile points. The most common value in a frequency distribution table is also called the *mode* for the frequency distribution.

Visual Representation of Pattern: Bar Charts and Histograms

Associated with a frequency distribution table is its graphical representation in the form of a bar chart with bars separated from one another when the variable can only take on integer and not fractional values, or a histogram with adjoining bars when the variable can take on fractional values. The height of a bar (with one bar for each value, or for a group of values when the data values are grouped) is proportional to the frequency of the value represented by the bar in the population.[2] Figure 8.1 shows a histogram for the data presented in Table 8.1. The histogram makes evident other aspects of pattern in the data—for example, the symmetry of the data; the relatively rapid drop-off of frequency counts as one moves away from an angle of about 40 degrees; and the single, isolated projectile point with an angle of 75 degrees. The mode at the angle of 40 degrees is easily seen in Figure 8.1.

Figure 8.1: Histogram for tip angle, 4VEN39 projectile points



Qualitative Aspects of Patterning

Patterning can be expressed in terms of features characterizing the histogram or bar chart. Features of interest are (1) the mode: the value that occurs most frequently in the population of values[3]; (2) whether the histogram is unimodal (that is, it has a single "peak" in the distribution of values as is the case in Figure 8.1) or multimodal (more than one peak in the distribution of values, though each "peak value" need not have the same frequency of occurrence); (3) whether the histogram is symmetric; and (4) whether there are extreme values—sometimes referred to as outliers[4]—located beyond the general pattern of values displayed in the histogram. In addition, another aspect of patterning that will be considered in the next chapter relates to the "peakedness" of a single peak. With regard to these features, the histogram in Figure 8.1 can be characterized as unimodal, moderately peaked, approximately symmetric distribution with a possible outlier at 75 degrees.[5]

Sometimes it is useful to approximate the histogram by a smooth curve. We can approximate the shape of a histogram with its "stair-stepped" appearance by a smooth curve that approximates the heights of the bars in the histograms. As the widths get narrower, corresponding to more accurate measurements used to define the boundaries for the bars in the histogram, the shape of the histogram approaches that of a smooth curve.

Constraints on choice of a smooth curve as an approximation for a histogram derive from the purpose for so doing. One purpose for using a smoothed curve is to compare the shape of the histogram with the curve for a normal distribution, a particular, smooth theoretical curve that plays a prominent role in statistical methods. The normal distribution occurs frequently for quantitative data for reasons expressed in the Central Limit Theorem (to be discussed below). Qualitatively, a normal distribution is unimodal, symmetrical, and has a bell-shaped curve. The bell-shape curve is given precisely by a mathematical equation, $y = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2}$, and has two parameters: (1) the population mean μ and (2) the population standard deviation σ. These two parameters specify which one, of all possible normal distribution curves, is being considered.

Quantitative Summary Measures of Patterning: Mean and Standard Deviation

In general, not just for the normal distribution, the population mean μ and the population standard deviation σ are two primary, summary quantitative measures for a variable X. The population mean is sometimes referred to as a measure of central tendency since it locates the "center" of the frequency distribution for a variable with respect to a numerical axis. The standard deviation σ is a measure of dispersion in the values of X around the population mean μ for the variable X.

The population mean μ may be computed as the arithmetic mean: $\mu = \frac{\sum x}{N}$, where N is the population size and Σ is a symbol indicating that the values following Σ (the variable values x measured over each of the members of the population) are to be summed up. Division by N, the population size, yields the population mean μ.

The standard deviation for a population is represented by the symbol σ and measures the degree to which the data values making up the population (for this example, the measurements displayed in Table 8.1 showing the angle of the point for each of the projectile points) are, on the average, dispersed away from μ. The formula for measuring dispersion relates to the equation for the normal distribution and is given by $\sigma = \sqrt{\frac{\sum (x-\mu)^2}{N}}$. Squaring changes the deviation $x - \mu$ into a positive number and places greater weight on values that deviate more from the mean μ. The square of the standard deviation, denoted σ^2, is called the variance of the variable X over the population of variable values. The variance σ^2 measures the average of the deviations squared, $(x - \mu)^2$ and so, in words, the standard deviation is the square root of the average deviation squared.

For the special case of a single artisan making one type of artifact, the value of σ measures the extent to which the artisan is exercising control over variation in the values x realized on the artifacts produced by this artisan for the aspect of the artifact represented by the variable X. A small value for σ indicates a high degree of control. For a heterogeneous population made up of artifacts from several artisan producers, the magnitude of σ is more complex and may be due to (1) the degree of control over the values x exercised by each artisan; (2) differences in degree of control by different artisans; and (3) differences among the artisans in the mean value of X for all artifacts produced by an artisan.

Statistical Patterning and Artifact Production

The focus on "patterning in the aggregate" in statistical analysis introduces a major constraint that relates directly to typology construction. The patterning is aggregate specific and so any change in the members of an aggregate can change the pattern and thereby may lead to change in the interpretation made of an object when reference is made to the pattern in which it is embedded. This underscores two difficulties that arise with

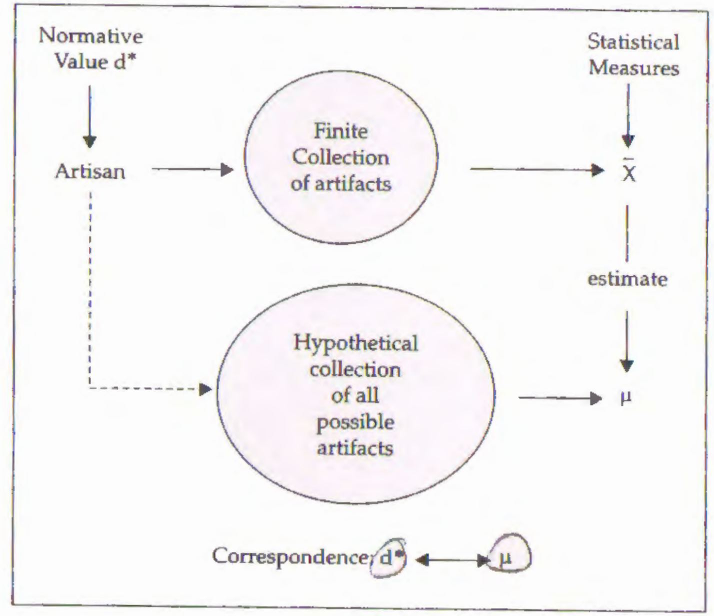
analyzing heterogeneous data. First, patterning from different aggregates are mixed together and the patterning of the combined data collection brought forward for analysis is now a combination of the patterning in the different aggregates and the relative, usually unknown proportion of each homogeneous aggregate in the collection as a whole. Second, patterning is a consequence of the process (or processes) underlying the production of the objects brought forward for statistical analysis. Hence, the pattern expected for a particular process needs to be identified in order for connection to be made between statistical pattern and characteristics of the process for the production of artifacts used by the artisan.

Connection Between Statistical Concepts and Cultural Concepts

We can relate a normative (i.e., culturally shared) value d^* for a culturally salient dimension D to a statistical parameter μ by introducing the idealized, hypothetical population of all entities that were or could have been produced by the process that gave rise to the empirical collection of entities actually produced. The process in question might be the technique of pottery production, flint knapping, basket making, and so on. The reason for introducing this hypothetical population stems from the fact that the mean value for a variable measured over a population of empirical entities depends on the historically contingent set of objects that were actually produced, and would most likely have a different value had more or fewer objects been produced. Thus, the mean value measured over a population of empirical entities is determined by the historical fact of which objects were actually produced, whereas our interest is in using statistical concepts to represent characteristics such as d^* for the process(es) guiding the production of artifacts and not just the contingent, summary properties of the objects produced using that process. The latter provides descriptive information about what was produced, whereas we are interested in ascertaining properties of the process underlying the production of artifacts responsible for what was produced.

We can relate the shared, or normative, value d^* for the dimension in question to the statistical parameter μ for a population defined to be all possible artifacts that were produced or could have been produced in accordance with the value d^* (see Figure 8.2). By *process* is meant not only the technique used for the production of artifacts, but the conceptual constraints that affect how that technique is implemented as discussed in the previous chapter for the *chaîne opératoire* concept. For artifacts with a culturally salient dimension D, we assume that one of the conceptual constraints is a shared value d^*—that is the intended value for the dimension D. The connection between the statistical parameter μ and the shared, intended value d^* then arises through the fact that d^* will, under broad

Figure 8.2: Correspondence of the set of artifacts actually produced using norm d* with the sample mean $\bar{x}$ and of the set of all possible artifacts using norm d* with the population mean μ



assumptions, be the mean of the values for the (hypothetical) population P of all possible artifacts that were—or could have been—produced, keeping fixed the mode of production and the intended value d^*. More precisely, as long as the distribution of manufacturing errors during the production of artifacts that leads to the actual values d realized on artifacts rather than the intended value d^* is symmetric with respect to d^*, then the population P will have mean equal to d^*. The symmetry assumption is a formal way of saying that there is no systematic bias in the production process that would lead to the actual values d consistently under- or over-representing the intended value d^*. The symmetry assumption will be satisfied if the production process matches the assumptions of the Central Limit Theorem to be discussed in the next section.

The statistical population characterized by $\mu = d^*$ cannot be an empirical population in the usual sense of a well-defined set of actual objects, but must be the hypothetical population that would be obtained if the process of artifact production were continued indefinitely. For any empirical population, the value of μ would not represent (except coincidentally) the intended value d^* for the dimension in question since the mean of D for an empirical population is the average value of that dimension for the objects the artisan happened to make.[6] Further, an empirical

population—such as the population of all objects actually produced by the artisan, keeping fixed the intended value d^* for the dimension in question—is a sample from the hypothetical population P of all possible objects that could be produced keeping fixed the intended value d^*. More generally, any empirical population of actual artifacts, however defined, will be a sample from the hypothetical population P: "[T]he values … are interpreted as a *random sample* of a *hypothetical infinite population of such values as might have arisen in the same circumstances*" (Fisher 1954: 6–7, emphasis added; see also Cox and Hinkley 1974; Read 1989b).

The criterion of a well-defined population of empirical entities is still applicable, but in modified form with another criterion that needs to be added. First, rather than just a well-defined empirical population, we now require that we have a well-defined *sample* of artifacts with respect to the population of all possible artifacts since any finite collection is a sample from the hypothetical population P. Second, the sample must be representative of the population of all possible artifacts from which it is drawn. By *representative* will be meant that estimates of population parameters such as μ and σ based on the sample mean and the sample standard deviation[7] are not biased; that is, the estimates average out precisely to μ and σ in the long run over all samples obtained in the manner specified. Random sampling of a population is one way to ensure representativeness. If we can consider each artifact produced by an artisan to be a random sample of size $n = 1$ from the population of all possible artifacts that could be produced keeping fixed the production process, then a collection such as "all pottery objects made by potters sharing the same conceptualization about pottery form and size" will be a random sample from the population of all pottery objects that could have been produced under the conditions stipulated in the sample definition.

The validity of defining for analysis a collection such as "all pottery objects made by inhabitants of the settlement" now needs to be assessed against the criterion of representativeness in addition to the criterion of well-defined. That is, even if the empirical collection is well defined, it may not be representative of any single process. There may be multiple processes incorporated in the production of pottery objects; hence, an empirical collection defined in this manner may be statistically valid with regard to the criterion of a well-defined empirical population, but not valid in terms of being a representative sample from a population of all pottery objects that could have been made while keeping fixed the process by which the pottery objects were made. In other words, the statistically valid empirical population may be heterogeneous from the perspective of the production of artifacts, and patterning discerned for such a population will represent both the effects of specific production processes and the relative quantities of artifacts produced using each of these production processes. An example of this effect on patterning will be seen for patterning among the Upper Paleolithic end-scrapers analyzed in the next chapter.

For the population of all artifacts that could have been produced, the correspondence between d^* (the normative value) and μ (the population mean) now allows us to interpret the statistical parameter μ as representing a cultural, normative value when the dimension D is a culturally salient dimension. For this situation, the mean measured over a set of empirical artifacts becomes an estimate $\bar{x}$ of μ—hence an estimate of the normative value d^*. Consequently, from this perspective, a "population" defined in terms of artifacts that were actually produced is simply a sample from the population of all possible entities, and its mean is a value $\bar{x}$ that estimates the population mean $\mu = d^*$.[8]

Expected Statistical Patterns: Unimodal and Normal Frequency Distributions

As we have discussed, the aggregates relevant for archaeologically meaningful statistical analysis of quantitative dimensions are usually not known a priori. Instead, they are to be determined through dissection of the data set brought forward for analysis in accordance with deviation from the expected statistical patterning for a dimension that is culturally salient in the production of artifacts of a given type. For a variable X, where variation in the measurements obtained for that variable over a collection of artifacts is the consequence of the pragmatic inability of the artisan to make exact the dimension being measured by X, we may invoke the Central Limit Theorem of statistics to determine a predicted pattern for the measurements obtained over a collection of artifacts when all of the artifacts were produced with a single intended value for the dimension that is being measured. The Central Limit Theorem may be stated in a number of ways, but the form of the theorem most directly useful for the construction of artifact typologies relates deviation of a measurement from the intended value to the sum of a random sample from a set of effects, with each effect changing the intended value by a small amount. The theorem states that under these conditions the observed measurements will tend to have a normal distribution, with the shape of the observed distribution of measured values being closer to a normal distribution when there are a greater number of small effects affecting the intended value.

Less abstractly, suppose the artisan desires to make pots whose opening has diameter d^*. When the potter makes a pot, he or she actually produces a finished pot with diameter d, where $d \neq d^*$. The difference, $\Delta d = d^* - d$, may be posited to arise from a series of small effects that affected

the potter's ability to make a pot with diameter d^*. The wetness of the clay may have had an effect; the speed with which the potting wheel was turning (assuming the pot was made with potter wheel technology) may be slightly different from one pot to the next; the potter may be tired; the potter may have been distracted while making the pot; the firing of the pot after it was made may have been done at a slightly different temperature; and so on. Each of these effects may have added or subtracted a small amount from the intended diameter d^*. For this situation, the Central Limit Theory asserts that if a collection of pots are produced, each having the same kind of effects affecting the deviation of the final diameter d from the intended diameter d^*, then the values $\Delta d = d^* - d$ will tend to have a normal distribution and the closeness of fit to a normal distribution increases without limit as the number of effects summed together increases without limit. In practice, the approximation will be very close to a normal distribution when the sum is based on about $n = 30$ small effects and the approximation will be reasonably close to a normal distribution when it is based on 5–10 small effects.[9]

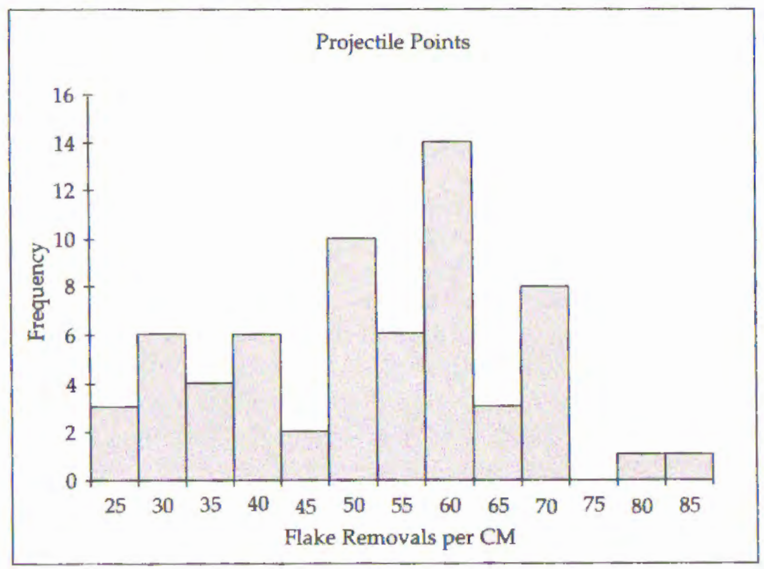
A range of 5–30 small effects responsible for the difference between the realized value d and the intended value d^* desired by the artisan is not unreasonable for artifact production, since each action made by the artisan while producing the artifact can introduce a small error. Consequently, the expected pattern for the values measured over a collection of artifacts will tend to be a unimodal—if not normal—distribution when (1) all artifacts are produced with a single intended value d^* for that dimension; (2) the reasons for the small effects responsible for deviation from the value d^* on an artifact are the same (or essentially the same) for all artifacts in the collection; and (3) variation in the magnitude of each of the small effects is randomly distributed over the artifacts in the collection.

Heterogeneity in a collection of artifacts corresponds primarily to violation of assumption (1). Variation in the degree of control or in the method of production among artisans could lead to violation of assumption (2). Variation linked to artifact type in the degree of control exercised in the production of artifacts could lead to violation of assumption (3). Further, Rouse's distinction between a mode and an attribute relates to assumption (1) through the mode being a dimension where a single value d^* for the dimension was shared across all artisans. In contrast, an attribute corresponds to a dimension of an artifact for which artisans may differ from one person to the next with regard to the intended value for that dimension and this would be in violation of assumption (2). The angle for the tip of a projectile point satisfies the condition for being a mode since the effectiveness of the arrow for killing an animal will be related to the angle of the tip of the projectile point. For this variable, we in fact have an approximately normal distribution of values for the projectile points, as can be seen in Figure 8.1.

For a dimension or variable that is not constrained by a shared normative, or intended value, the shape of the histogram for a frequency distribution will be determined by whatever process or processes leads to the values of the variable measured over the data at hand. Consider the variable, number of flake removals per centimeter, that was measured for the projectile points. There is no reason to assume that projectile points were knapped by artisans who shared a normative value for the number of flake removals. Instead, the latter is likely to be happenstance and depends on the nature of the material, the extent to which the artisan made a point relatively quickly or with greater care, and so on. For this variable, we would not expect an approximately normal distribution since there is no intended value around which the actual value will vary according to a fixed set of possible error factors. In fact, the histogram for this variable is difficult to characterize as can be seen in Figure 8.3 and stands in marked contrast to Figure 8.1 for the angle of the tip of a projectile point.

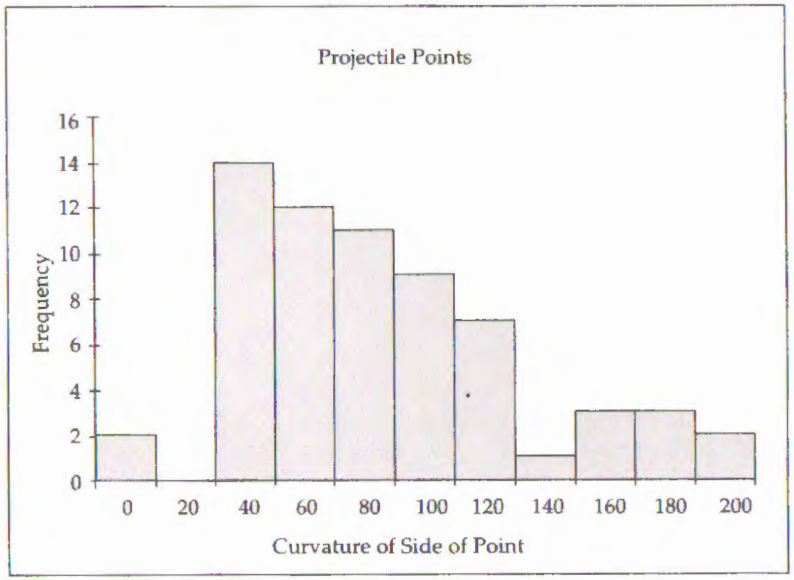
Lack of a clear unimodal, and approximately normal histogram is the sign of a dimension that is not a mode and thus was not subject to a normative or intended value by the artisan. We can apply this criterion to the curvature of the sides of the projectile points. The histogram for the side curvature is clearly neither a normal distribution nor even unimodal

Figure 8.3: Histogram for number of flake removals per centimeter, 4VEN39 projectile points



and the pattern for the histogram cannot easily be characterized (see Figure 8.4). Hence, we initially hypothesize that the curvature of the side of a projectile point was not under normative control by the artisans.

Figure 8.4: Histogram for the side curvature, 4VEN39 projectile points



This hypothesis, however, is subject to an alternative interpretation: that the projectile points are not a single type and that the pattern we observe in Figure 8.4 has been summed over several types of projectile points. We have no reason to assume that the data set brought forward for analysis is already a homogeneous data set. Consequently, we need to address the other aspect of the double bind—the possibility that the data brought forward for analysis are composed of more than one type of projectile point. To address this question, we need to consider how we might subdivide the data set brought forward for analysis using culturally relevant distinctions.

Subdivision Criterion

If we have two culturally distinguished types of artifacts, then for the dimensions of the artifacts that are under normative control by the artisans, we expect (as discussed above) to find a unimodal, approximately normal distribution for a histogram based on a single artifact type. Among the culturally salient dimensions, there must be at least one dimension where

the normative values for the two types of artifacts are not the same. Otherwise, there is no culturally salient basis for distinguishing between the two types of artifacts. A histogram for this dimension will have a bimodal distribution, with each node centered at the relevant normative value for the artifact type in question. If we assume that an artifact can be assigned unambiguously to one or the other of the two types by the artisans, it follows that the two nodes will not overlap. If the modes did overlap, then an artifact that falls within the area of overlap cannot be distinguished by the type to which it belongs; it can only be assigned probabilistically to one type or the other and not with certainty by the artisans or users, contrary to our initial assumption. Hence, we may assume—at least as a first approximation—that for two emically distinct types of artifacts, there will be a culturally salient dimension for which a histogram will be bimodal and without any (or very little) overlap in the two modes. Further, the shape of the distribution for each of the modes should be unimodal and approximately normal.

We can reverse this observation and use it as a basis for subdividing a collection of objects into subgroups.

> Subdivision Criterion: *A set* S *of objects will be said to be objectively subdivisible into* n *subgroups* $S_1, S_2, \ldots, S_n$, *if for any pair of subgroups* S_i *and* S_j, $i \neq j$, *there is some dimension* D *such that either (1) if the dimension* D *is represented with qualitative attributes, then objects in* S_i *share one (or more) attributes and objects in* S_j *share a different attribute(s) for the dimension* D; *or (2) if the dimension* D *is represented with one (or more) metric variables* V, *then the pair of subgroups* S_i *and* S_j *will have (at least) a bimodal distribution with the objects in* S_i *forming one mode and the objects in* S_j *forming the other mode in the measurement space determined by the variable(s)* V (modified from Read and Russell 1996).

The dimension *D*, appropriate for one pair of subgroups, need not be the same dimension appropriate for another pair of subgroups since "the world [of artifacts] is highly structured" (Kempton 1981: 197).

The bimodality criterion requires elaboration. A bimodal distribution may occur for reasons unrelated to having a culturally salient dimension that distinguishes artifact types, such as mechanical constraints in the production process leading to the nonoccurrence of some dimensional values. When unintentional reasons for a bimodal distribution can be ruled out, then a gap separating the modes of the bimodal distribution implies that the pattern is intentional. However, intentionality can be with respect to a single artisan, or it can represent a concept shared by several

artisans regarding artifact production. Bimodality due to the intentionality of a single artisan need not be statistically distinguishable from bimodality common to several artisans sharing a conceptual basis underlying the bimodality. Separating individual intentionality from intentionality arising through shared concepts may depend on criteria other than the pattern of values in the histogram. Despite Spaulding's (1953) intent that statistical methods would provide an objective means to distinguish culturally salient types without reference to space and time distribution of artifacts, distinguishing between a cultural and an individual artisan basis for the bimodality may require additional evidence (such as the spatial and temporal distribution of the histogram pattern for the artifacts), as argued by Krieger (1944).

While bimodality in the frequency distribution for a variable provides an objective basis for subdividing a data set into subgroups, the distribution pattern of the variable values for each of the subgroups provides an additional criterion for determining if the variable measures a culturally salient dimension. When the variation in the values in each subgroup represents errors in attempts to produce an artifact according to a normative value, we expect the distribution pattern to be approximately a normal distribution. When the variation is happenstance and does not represent errors in attempts to arrive at a normative value, the frequency distribution need not match that of a normal distribution and may lack any clear pattern (compare Figure 8.1 with Figures 8.3 and 8.4). Hence, absence of an approximately normal distribution for the measurements over a homogeneous subgroup can be used to identify a variable measuring a dimension that may not be culturally salient.

Recursive Subdivision Procedure

Based on this background discussion on the relationship between patterning discernible in the aggregate and normative/culturally relevant aspects of artifacts, we may now set forth a procedure—based on the subdivision criterion—for subdividing a heterogeneous collection of artifacts, C, brought forward for analysis into homogeneous, culturally salient subgroups. The subdivision process will use the following recursive procedure:

Step 1: Determine if there is a qualitative variable (absolutely qualitative, qualitative, or bifurcation qualitative) that measures a culturally salient dimension D.
Step 2: Subdivide the data set C into subgroups based on D.
Step 3: Apply Steps 1–2 recursively to each of the subgroups distinguished in Step 2 until no more subdivisions may be made with qualitative variables.

Step 4: Determine if there is a quantitative variable, or set of variables, that measures a (potentially) culturally salient dimension D for any subgroup C^*, determined through Steps 1–3.
Step 5: Subdivide the data set C^* into subgroups when there is (at least) bimodality for D.
Step 6: Apply Steps 4–5 to each of the subgroups distinguished in Step 5, if any.

We begin with the attributes for qualitative variables since these can be identified on individual artifacts without reference to patterning over an aggregate of artifacts. The problematic part of subdivision resides with quantitative, not qualitative, divisions; the former depends upon the patterning for quantitative measurements that can be discerned in the aggregate. Hence, potential sources of heterogeneity—such as patterns for quantitative dimensions being specific to qualitatively different groups of artifacts—must be removed to the extent possible prior to analysis of quantitative measurements. Once patterning for quantitative measurements has been worked out for qualitatively distinct groupings, comparison can be made across these groupings for quantitative patterning in the form of bi- or multi-modality in the distribution of values for a culturally salient dimension D.

Typologies based on qualitative aspects of artifacts have implicitly, if not explicitly, used Steps 1–3. These steps underlie the intuitive, gestalt-oriented approach discussed by Adams and Adams (1991), which primarily identifies qualitative distinctions for patterning among artifact attributes. However, Adams and Adams conflate identifying qualitative distinctions relevant for the artifacts in question with specific analytical goals such as developing a time-sensitive typology. The latter implies that some of the classes in the typology may be heterogeneous with respect to qualitative, culturally salient dimensions, which can be problematic when subdivisions are to be based on quantitative dimensions that are valid only for some qualitatively distinguished groups.

Step 4 assumes that a culturally salient dimension D is embedded within the set of measures made on the artifacts. The archival property for the aspect, or aspects, of the artifacts for which culturally salient dimensions are relevant is a way to meet the assumption underlying Step 4. While the form of an artifact is frequently taken as the aspect of the artifact being analyzed, Step 4 need not be limited to measurements based on form. Though we may not know the relevant dimensions prior to the analysis we are conducting on the artifacts, we often have prior information on production technologies, possible functional constraints on artifact

design, and so on, for the artifacts in question that may suggest potentially relevant dimensions for artifacts.

Step 4 is implemented by examining each of the variables that have been measured over the artifacts for the presence of multimodal distributions. If no multimodal distributions are found, bivariate scattergram plots for all pairs of variables are constructed to determine if groupings are present in a two-dimensional representation of the data. Failing that, three-dimensional plots might be examined. If this "bottom-up" approach fails to find any dimension *D* that can be used to divide the data set, then a "top-down" approach (such as principal components) can be used to reduce the overall dimensionality of the set of variables measured over the artifacts, and the search process for multimodality repeated using the principal components as new variables. If none of these finds a relevant dimension *D* that can be used for subdividing the data set, then we may either conclude that the data set is homogeneous as it stands, or that the set of variables selected for measurement fails to capture a dimension, *D*, that permits subdividing the data set objectively into subgroups. In the latter case, we would begin the analysis again with new variables if we are not convinced that the data set is homogeneous.

We will illustrate the recursive subdivision procedure with two data sets that have been discussed in the literature. The first data set consists of the previously mentioned projectile points found at the California site 4VEN39. Initial analysis of these points (Christenson and Read 1977) focused on issues relating to numerical taxonomy methods and the use of principal component analysis to remove variable redundancy. The authors demonstrated that clustering based on all the variables measured over the projectile points failed to find two obvious clusters—concave- versus convex-based triangular points—even though the variables were carefully selected and included measurements of the base region of the points. However, when outliers were removed and variable redundancy was eliminated by basing the clustering on the principal components, two nonoverlapping clusters that corresponded to the concave base and convex base points were found.

These results were critiqued subsequently on the grounds that the clustering procedure used by the authors supposedly was not sensitive to the criterion of "internal cohesion and external isolation," that the variables were inappropriate, and that the clusters did not have independent corroboration (Cowgill 1982; Hodson 1982). The last criticism ignored the fact that the convex and concave base points correspond to two well-established point types in southwestern archaeology: Cottonwood Triangular and Cottonwood Leaf Shape projectile points (Thomas 1981). The other criticisms assumed, but did not demonstrate, that a different clustering procedure would have found supposedly valid clusters with unweighted variables. However, no other clustering procedure—including *k*-means clustering with $k = 2$ clusters specified—has been able to identify the two obvious groupings using unweighted variables (Read 1989b) since the assumption of convergence on valid clusters as the number of unweighted measurements is increased is invalid (see Appendix).

We will use this data set to demonstrate that the recursive subdivision procedure not only correctly identifies groupings that are easily identified using intuitive means (such as sorting pictures of the projectile points), but is also able to uncover groupings that are not evident using intuitive sorting and depend on quantitative measurements for their discovery and definition. The recursive subdivision procedure also allows us to determine what are the modes (as opposed to attributes) for these projectile points and which variables are measuring the modes. We will refer to these results regarding modes and variables in Chapter 10 when we take up the recent recasting of artifact analysis in Darwinian evolutionary terms. Finally, we construct a typology for the projectile points that goes beyond the Cottonwood Triangular and Cottonwood Leaf Shape classification.

The second data set consists of a series of pottery vessels (jars, pitchers, and necked bowls) from the late Neolithic site located at Niederwil, Switzerland discussed briefly in Chapter 5. Robert Whallon analyzed this data set in an attempt to find "'real' discontinuities in the distribution of data along one or more axes of variability" (Whallon 1982, p. 140, note 2). We will use this data set to compare the results of the recursive subdivision procedure with the analysis presented by Whallon by focusing on whether a taxonomic structure resolves some of the ambiguities found by Whallon in his paradigmatic typology representation of the vessels.

Application of Recursive Subdivision to Projectile Points

The projectile point data set *S* does not have any qualitative variables that would allow the data set to be divided into qualitatively distinct subgroups. Hence, we begin the analysis of the projectile points with Step 4 by constructing a histogram for each of the variables measuring some aspect of the morphological form of the points to see if any of the variables has a bimodal distribution. We find that the variable, Base Height, is bimodally distributed (see Figure 8.5). The possible ambiguity of the points with Base Height = 0 is clarified in a scattergram plot of Base Height versus Thickness (see Figure 8.6). The points with Base Height = 0 are clearly part of the right cluster of points. A *k*-means cluster analysis

Figure 8.5: Histogram of Base Height, 4VEN39 Projectile Points

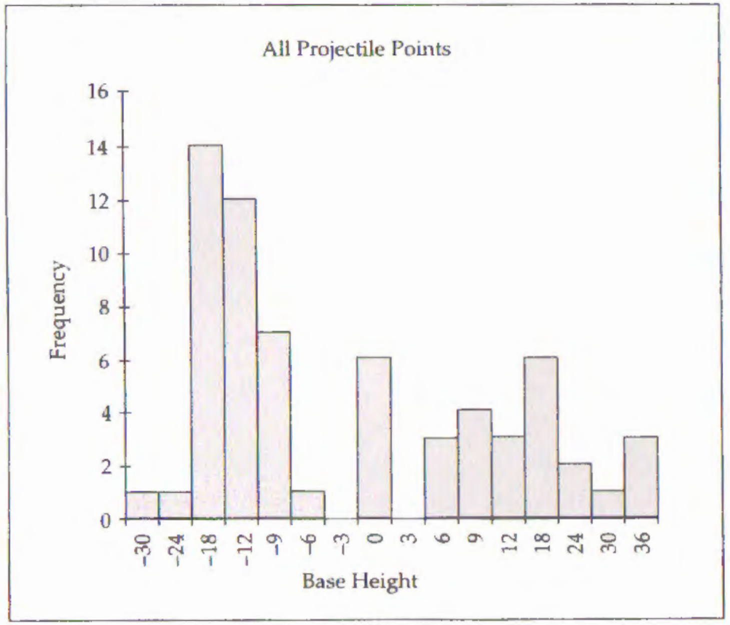
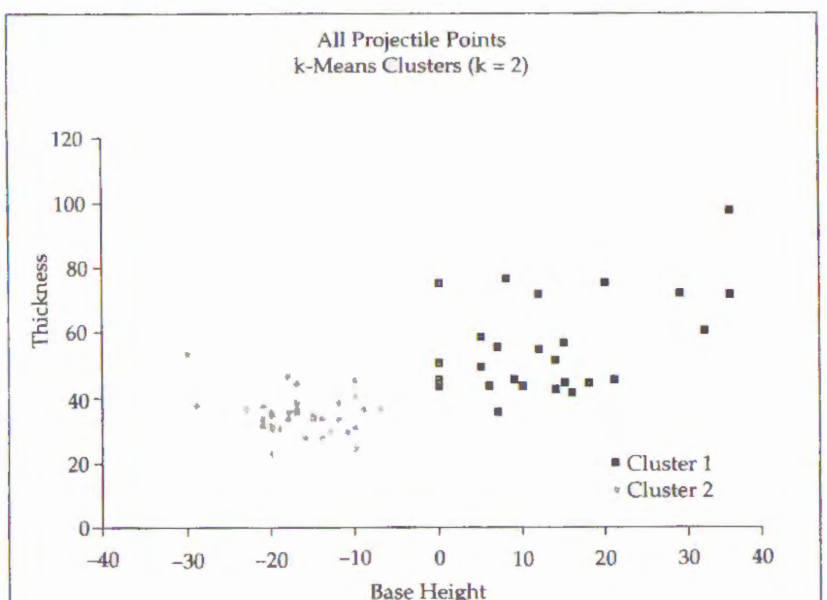


Figure 8.6: Scattergram plot of Base Height versus Thickness, 4VEN39 Projectile Points



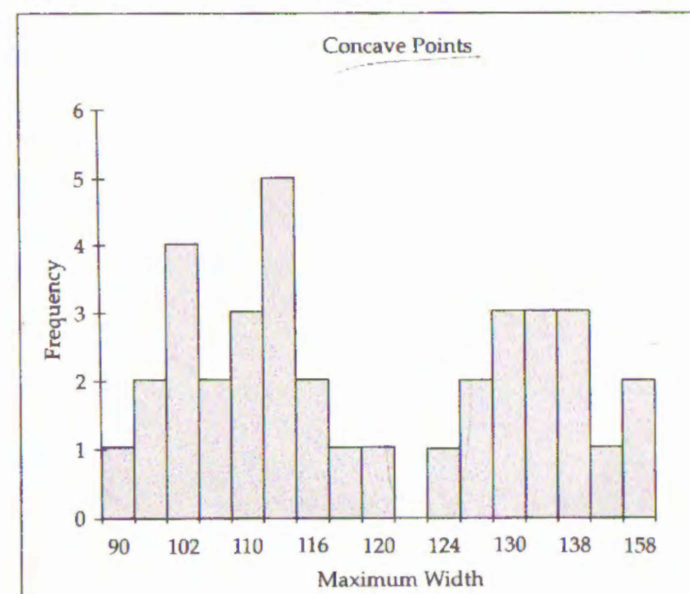
with $k = 2$ and based on the variables Base Height and Thickness confirms the division into two subgroups (see points marked 1 and 2 in Figure 8.6). The nonoverlapping bimodal distribution implies that the artisans making these projectile points nominalized the base height dimension. Hence the property P distinguishing these two groups is projectile point base height.

We now divide the data set S into two subgroups, S_1 and S_2, where S_1 contains all points with Base Height < 0 (concave base points) and S_2 contains all other points (convex base points). The conceptual division between concave and convex base points is culturally salient since there is no mechanical reason for the bimodal distribution of Base Height. The concave points have an intended base height of about 18 millimeters, whereas the convex points have no clear modal value and their base heights do not appear to be under any conceptual constraint.

Concave Points Subgroup

We repeat the procedure on each of these subsets, beginning with the subset consisting of concave base points. We find that the subset S_1 of concave points has a bimodal distribution for the variable Maximum Width as shown in Figure 8.7, with a division between the two modes at a width of 122 millimeters. Each of the two modes has an approximately

Figure 8.7: Histogram of Maximum Width for Concave Points



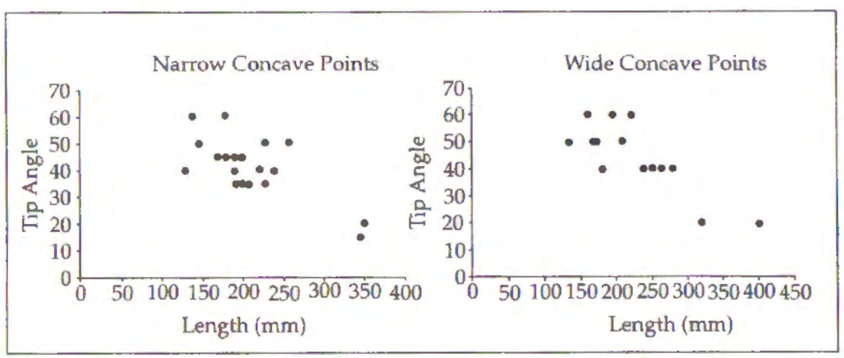
normal distribution. The nonoverlapping bimodal distribution implies that the artisans making these projectile points nominalized the width dimension. Hence, the property P distinguishing these two groups is projectile point width.

We now divide the subgroup S_1 into the subgroups S_{11} and S_{12}, where S_{11} contains all concave points with Maximum Width < 122 millimeters and S_{12} contains all other concave points. The two groups can be characterized as Narrow and Wide concave base points. The narrow points have a mode of 110 millimeters with a sample mean $\bar{x} = 107.3$ ($s = 8.31$, $n = 21$) and the wide points a mode of 134 millimeters with sample mean $\bar{x} = 134.5$ ($s = 9.94$, $n = 15$). Because the standard deviations for each of the two groups (treating each group as a sample from a population of concave points) are not statistically different ($F = 1.44$, $0.20 < p < 0.25$), they differ only with respect to intended width value.

We repeat the process for each of the two subgroups S_{11} and S_{12}. For these subgroups, we find bimodal distributions for the point length and the tip angle, with a mode only containing two points for each of the two modes. The pattern for these two variables is clearer in a scattergram plot of point length versus tip angle where two of the projectile points stand out, for each of the Narrow and Wide categories, as being much longer than the bulk of the concave projectile points (see Figure 8.8). We next examine the bimodal differences in length for these points with respect to the overall shape of the concave projectile points.

With isometric shape change, the tip of the point should not vary with changes in the size of the point and measures of form—such as length and width—should be highly correlated. However, the correlation between length and width is statistically zero ($r = -0.02$ for S_{11}, $r = -0.09$ for S_{12}). In addition, as can be seen in Figure 8.8, there is a decided negative

Figure 8.8: Scattergram plot of Length versus Tip Angle for Narrow and Wide concave points

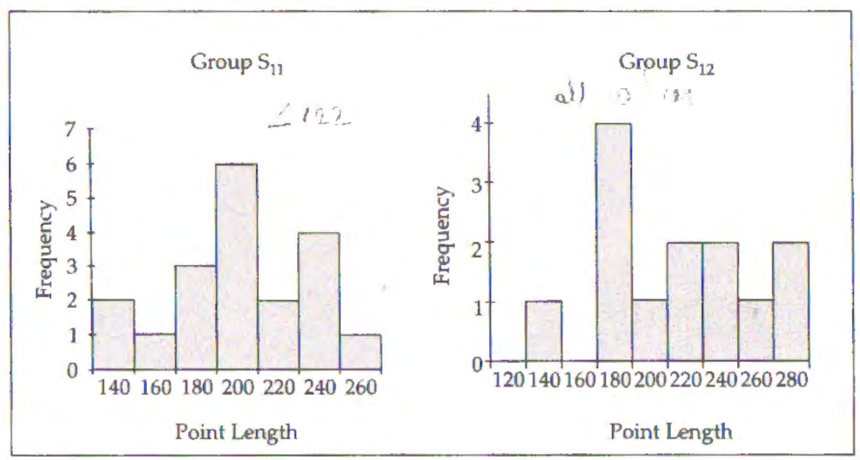


correlation between angle of tip and length of point ($r = -0.71$ for S_{11} and $r = -0.81$ for S_{12}). The negative correlation between angle of tip and length of point and the zero correlation between angle of tip and width of point suggest that the variation in the length of the points is due to breakage and resharpening of the projectile points. If so, the long projectile points in Figure 8.8 are unbroken points and all the other projectile points are resharpened projectile points.

Consistent with this interpretation is the lack of patterning for the length variable when excluding the whole points, especially for group S_{12} (see Figure 8.9), which would be expected if the lengths of the resharpened points were happenstance and simply the result of the chance event of point breakage. The four whole points, two from each of the groups S_{11} and S_{12}, are consistent with the division into Narrow and Wide points and show "internal coherence and external isolation" in a plot of Maximum Width versus Base Height (not shown) despite the small sample size. The bimodality of maximum width used to subdivide the concave projectile points into two subgroups is not affected by breakage and resharpening; hence, both the broken and unbroken projectile points can be unequivocally assigned to either subgroup S_{11} or S_{12}.

It appears, then, that the concave projectile points consist of two culturally salient types, Narrow and Wide concave projectile points. In addition, the points in the data set appear mainly to be resharpened points and the dimension most affected by resharpening—length—has a frequency distribution pattern consistent with length variation that is happenstance and not intentional. Four of the concave points are consistent with being unbroken points, and the bimodal distribution that separates these from

Figure 8.9: Left diagram: histogram of Point Length for group S_{11}. Right diagram: histogram of Point Length for group S_{12}



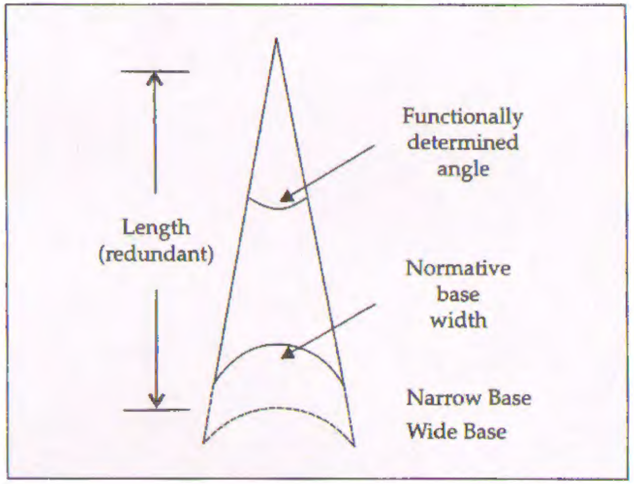
the other concave points (see Figure 8.8) is an example of a "mechanical" rather than an intentional bimodal distribution since the bimodality is most likely due to breaking and resharpening of whole points.

Of the original eight variables measuring some aspect of the form of the concave base projectile points, it appears that three dimensions are modes: Angle of Tip, Maximum Width (= Base Width), and Base Height. Length, as it occurs on the recovered projectile points, represents the original length of a projectile point in some cases and the length of the point after breakage and resharpening for most of the concave points. Correspondingly, the histogram for length is not consistent with a culturally salient dimension. Length may have originally been a mode, but the only relevant data are the small sample of unresharpened points and the sample size is insufficient for determining the shape of the frequency distribution for the point length of unresharpened projectile points.

The value for the angle of the tip is likely to have been constrained by mechanical/functional aspects of point usage in hunting and is the same for the Narrow and the Wide concave points; hence, the tip angle should not be, and is not, distinguishable between the Narrow and Wide concave points ($t = 0.95$, $0.30 < p < 0.35$, df = 33). Base Height has a unimodal, slightly skewed distribution for the narrow concave points and a possible overlapping bimodal distribution for the wide concave points due to more points with a small base height than would otherwise be expected. The overlap, along with the excess number of points with a short base height, could result from resharpening that may have reduced the base height through modification of the tang portion of the base of the projectile points. Assuming the angle of the tip is determined by mechanical/functional constraints, the outline of a triangular projectile point is determined by the base width and the (fixed) angle of the tip, thereby making the length of the projectile point redundant (see Figure 8.10). Hence, we can characterize the two types of concave projectile points as having a triangular shape with a functionally constrained tip angle and a base width that represents the instantiation of two intentional, culturally salient values.

The two culturally salient width values raise a question about the relevant social group for the production of each of the two width values since it is unlikely that the width difference is a functional difference relating, say, to hunting differences (see Ellis 1997). A possible social unit for a culturally normative width value in the context of a prehistorical-Indian group in southern California is a single lineage. The fact that both types of concave points were found at the same site with comparable frequencies suggests production of both kinds of points in the same settlement. If so, the presence of two normative widths implies that the settlement consisted of two lineages. A pattern of multiple lineages residing in

Figure 8.10: Geometry of triangular projectile points



the same settlement is consistent with a society based on matrilineal lineages (Keesing 1975). It is not consistent with the residence pattern for patrilineal lineages in the southern California area. For example, the Cahuilla Indians—who lived to the east of the 4VEN39 site in the San Jacinto mountains—were a patrilineally structured hunter-gatherer society with each village based on a single patrilineal lineage (Bean 1972). 4VEN39 is close enough to the California coast to assume that it was part of the Chumash Indian sphere of influence. The Chumash were likely matrilineally organized since marriage residence was mostly matrilocal (Gamble et al. 2001), so it is plausible to posit that the inhabitants of 4VEN39 lived in a village based on two matrilineal lineages.

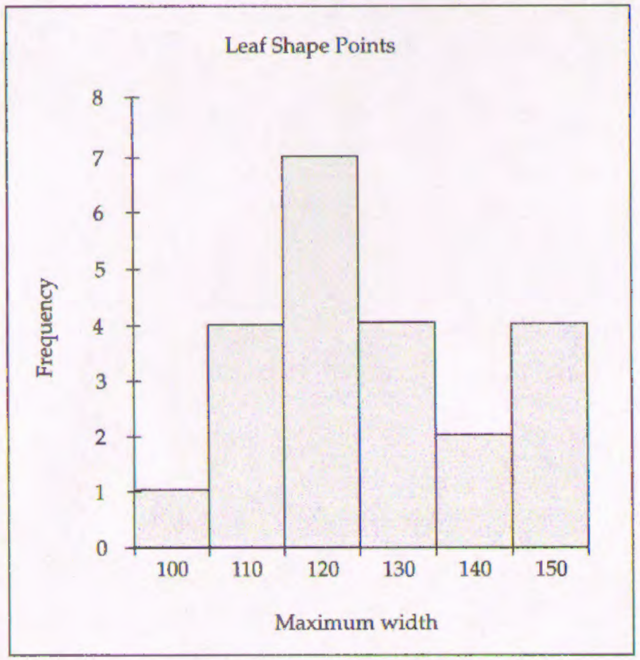
Convex Points Subgroup

The convex points have a leaf shape and several outliers in the form of individual points with dimensions outside any coherent aggregate. Collectively, the outliers do not form a coherent group. Three of these points are distinguished by comparatively large values for thickness and maximum width. The largest of these is most likely a blank. An additional group of three points are outliers with respect to maximum width and have values outside of the range for the bulk of the data and are idiosyncratic leaf shapes. Neither with these six outliers removed nor with them included is there any variable, or pair of variables, with a bi- or multimodal distribution. Consequently, after the outliers have been

removed, the convex base points form a single group of points lacking any basis for subdivision and the six outliers are individually unique leaf shape points.

The only variable that is close to a unimodal, approximately normal distribution for the group of leaf shape points is the maximum width of the points (see Figure 8.11), though at least two of the points have greater width than would be expected for a simple unimodal distribution. The maximum width determines the degree of leaf shape for the point outline and should be culturally salient if the points are conceptualized as having a single shape. Variation in the convex point length, another aspect of the leaf shape, appears to be affected by resharpening—thus giving the shorter convex points a fatter leaf shape than otherwise would be expected, based on the dimensions of the longer convex points that have not been resharpened. These longer points have a more needle-like shape.

Figure 8.11: Histogram for the leaf shape points



Since the base height frequency distribution for the convex points does not have a unimodal, approximately normal shape, it is not a culturally salient dimension (in contrast to base height for the concave points). The pattern of correlations among the variables for the leaf shape points

(see Table 8.2) does not show any pronounced pattern other than a moderate correlation of shape dimensions with thickness. Altogether, these data suggest that these points have an overall leaf shape that includes the base as part of a single conceptualization about shape and where the thickness of the point relates to the size of the points. A leaf shape is given by the length, width, and curvature of the sides of the leaf and so the shape dimension is not directly measured by any single quantitative measurement.

Table 8.2: Correlations Among Variables for Leaf Shape Points

	Length	Max Width	Thickness	Base Ht	Base Width	Tip Angle
Length	1.00					
Max Width	0.55	1.00				
Thickness	0.59	0.61	1.00			
Base Ht	0.30	0.15	0.50	1.00		
Base Width	0.41	0.48	0.35	0.57	1.00	
Tip Angle	–0.13	0.60	0.12	–0.05	0.11	1.00

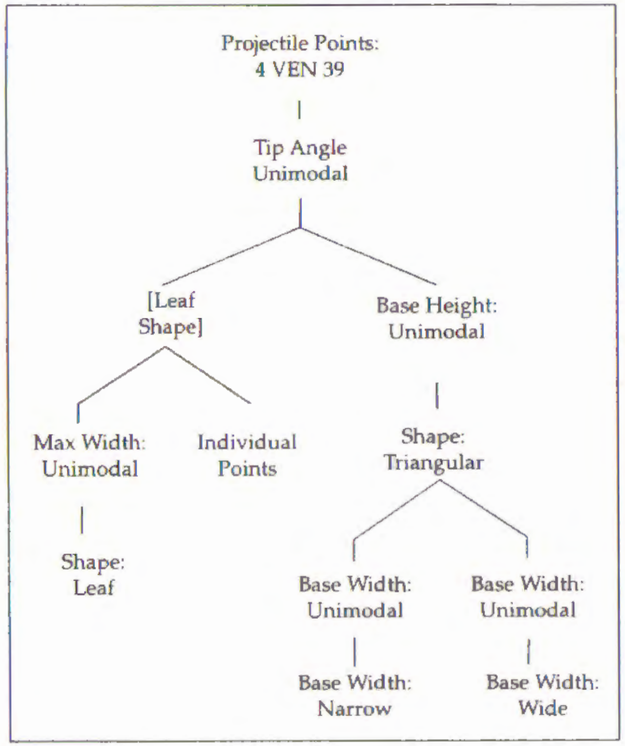
Typology for the 4VEN39 Projectile Points

We can now construct a typology for the projectile points at 4VEN39. First, we identify the cultural context as the settlement/village represented by the archaeological site 4VEN39. The projectile points were recovered using random sampling of space and time control was provided through vertically stratified sampling. There is no indication of either space-specific or time-specific variability in the points and so we may assume that the site is culturally homogeneous. The boundary for the cultural domain in which the manufacture of these points was located need not just be the site 4VEN39; other sites in the region may share the same cultural concepts regarding the construction of projectile points. If we had evidence of a space-specific or time-specific variability pattern among the projectile points, then we would initially subdivide the projectile points according to the space and time boundaries for that variability.

Of the variables that have been measured, a single one—tip angle—constitutes a mode for the collection of points as a whole. The tip angle has the same value regardless of the subdivisions in the point typology that is being constructed and for all subdivisions it has a unimodal, approximately normal distribution. We identify Tip Angle as a culturally salient dimension in the typology even though it does not give rise to any subdivisions (see top part of Figure 8.12).

The first division is based on the bimodal distribution for base height and allows for what we etically refer to as convex and concave points. However, only the concave points have a frequency distribution for base

Figure 8.12: Taxonomic structure for 4VEN39 projectile point typology



height with a unimodal, approximately normal shape. The base height for the convex points does not match the criterion for a dimension that is culturally salient. Hence, we do not use a concave/convex opposition in the typology; the evidence does not support the emic relevance of that opposition. Instead, the division needs to be by shape: leaf shape versus triangular shape (see Figure 8.12). Both these shapes appear to be culturally salient, as indicated by the distribution pattern for a measure of that shape, though the leaf shape points as a whole do not form a coherent group.

The collection of $n = 28$ leaf shape points appears to include six points that are isolated from the bulk of the leaf shape points on the basis of one or more aspects of shape. The remaining group of $n = 22$ leaf shape points appears to form a homogeneous group composed of a single, culturally salient leaf shape dimension. The leaf shape is partially measured by the quantitative measures length, maximum width, and curvature of the side of the point. Consequently, "leaf shape" per se does not determine a culturally salient, single class of projectile points

at 4VEN39: six individually unique points are also part of the $n = 28$ leaf shape points. When the six unique points are removed, the remaining $n = 22$ points appear to form a culturally salient group on the basis of the distribution pattern for maximum width. Hence, we distinguish between the grouping "[Leaf Shape]" and the class, "Shape: Leaf" in Figure 8.12.

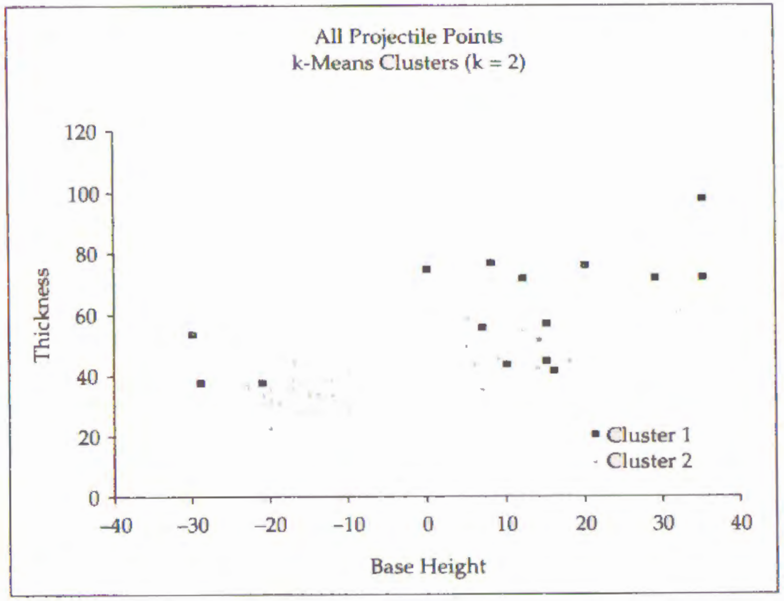
The other shape, triangular points, does constitute a class, Shape: Triangular, since there are no individually unique triangular points and the Base Height measurement is unimodal and approximately normal for these points, indicating that all triangular points were conceptualized in the same manner with respect to the concavity of the base. The class, Shape: Triangular, is then subdivided into two subclasses, Narrow and Wide, based on the bimodal distribution for the base width variable and the unimodal, approximately normal distribution for base width for the projectile points in each of these two classes.

Included in Figure 8.12 is the measurement that provides the basis for a culturally salient class and not simply a grouping of projectile points. The fact that we have a basis for grouping objects is not by itself sufficient for asserting the presence of a culturally salient class of which the objects are members. Instead, we need to demonstrate that the grouping is distinguished by a dimension whose frequency distribution for a variable measuring that dimension is consistent with the pattern of data values we expect for a culturally salient dimension relevant to the production of the artifacts in question.

The projectile point example demonstrates that the analytical double bind rendering numerical taxonomy and clustering methods inappropriate can be resolved using a recursive approach that identifies culturally salient dimensions as the analysis proceeds and subdivides the data set according to those culturally salient dimensions. The resulting typology for the projectile points is a taxonomy, not a paradigm. The taxonomic structure does not arise for a priori reasons, but as a consequence of the distinctions made during the data analysis. The form of the typology derives from the pattern of differences and similarities as conceptualized and enacted by the artisans and users of the artifacts, and thus has a structural form that must arise from analysis of the data and not from a priori conceptions about the form of a typology.

Finally, we note that the typological structure determined by using the recursive division procedure cannot be subsumed under the numerical taxonomy clustering methods that treat all variables with equal weight. The initial division into leaf shape and triangular shape points, based on the bimodal distribution for Base Height and Thickness, is lost, for example, even when a single additional variable—length—is added to the k-means, clear-cut, two variable cluster analysis based on Base Height and Thickness. Figure 8.13 shows the result of k-means cluster analysis

Figure 8.13: Misclassification of points with two groups specified for *k*-means clustering but including a third variable, length, that is independent of the distinction between concave and convex points



with $k = 2$ using the variables Base Height, Thickness, and Length. Not only are there misclassifications, but the points at the lower left and upper right extremes of the scattergram plot are grouped together in the same cluster. The two groups identified in the *k*-means cluster analysis crosscut the obvious shape difference in these projectile points. But perhaps more problematic than the error in misclassification is the lack of any information in the *k*-means cluster analysis signaling that the clusters are not "internally coherent and externally isolated."

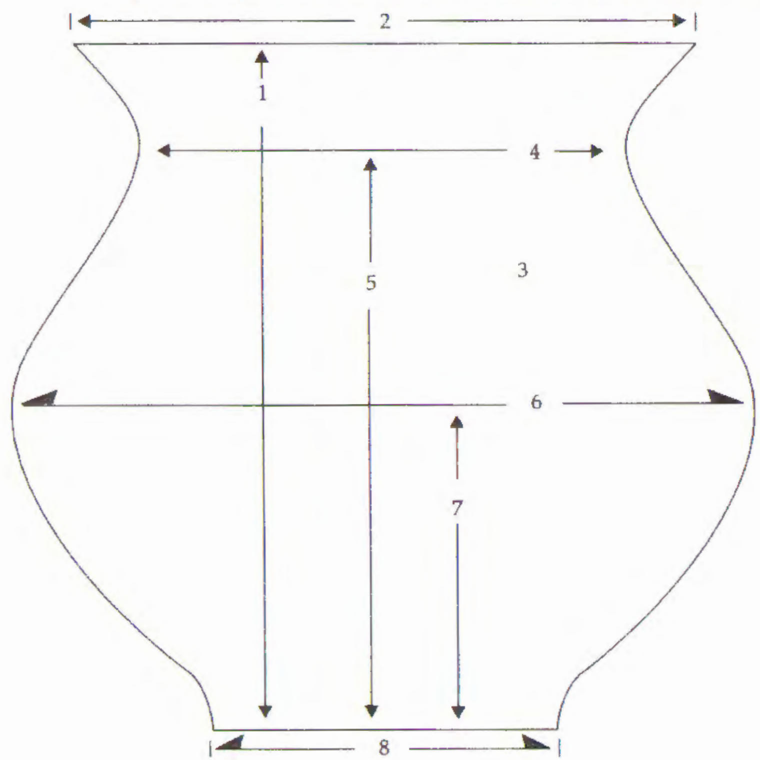
Application of Recursive Division to Pottery Jars

The Niederwil pottery collection discussed in the previous chapter consists of vessels ranging from squat to urn-like jars, including vessels with and without handles. Some of the vessels without handles have a wavy indentation (rim indentation) as part of the bottom portion of the pottery rim. Hence, we have purely qualitative differences based on topological differences (no handles, one handle, or two handles), bifurcated quantitative differences (rim indentation versus smooth rim), and quantitatively based shape and size differences. The sequence of recursive subdivision begins with the topological differences, then uses the bifurcated

quantitative differences, and lastly the shape and size differences. The first two divisions do not require any analysis since the basis for the division is a feature of a jar and is not based on "pattern in the aggregate." The third division will involve the kind of analysis illustrated above for the projectile points from 4VEN39.

The jars were measured with eleven variables, of which the first eight are shown in Figure 8.14. The remaining three variables relate to the curvature of the portion of the jar below the belly. The curvature was measured using the same system as discussed in Chapter 6—via (a) the length of a chord from the intersection of the maximum diameter of the belly with the side of the jar to the outer edge of the base of the jar; (b) the maximum height of the curve above this chord; and (c) the distance from the base to this maximum height. These measures on the portion below the belly of the jars do not play a role in the typology to be constructed for these jars and so are not shown in Figure 8.14.

Figure 8.14: (1) height of vessel; (2) rim diameter; (3) square root of cross sectional area; (4) neck diameter; (5) height to neck; (6) belly diameter; (7) height to belly; (8) base diameter. Modified from Whallon 1982



Step 1: Topological Division

The first division separates the jars with handles (five jars with one handle, one jar with two handles) from the jars without handles ($n = 57$) as topologically distinct categories. The shape and size of the jars with handles can be compared later in the analysis to the typology constructed for jars without handles to determine if potters simply attached handles to already existing shapes and sizes for jars or if the jars with handles are also distinctive in size and/or shape. We divide the data set into three groups: Jars with One Handle ($n = 5$), Jars with Two Handles ($n = 1$), and Jars Without Handles ($n = 57$).

Step 2: Bifurcated Quantitative Division

The jars are next divided according to whether the jar rims are indented on the underside of the rim. The pattern in question can be observed on individual objects, so we form two categories: Indented Rims ($n = 6$) and Smooth Rims ($n = 51$). None of the Jars with Handles have indented rims.

Step 3: Quantitative Shape Differences, Jars Without Handles, and Smooth Rims

When making a pottery jar, the potter must make decisions—explicitly or implicitly—regarding the height of the jar, the diameter for the belly of the jar, the relative location of the belly in the vertical dimensions of the jar, the diameter of the rim of the jar, the diameter of the neck of the jar, the relative location of the neck in the vertical dimension, and the diameter of the base of the jar. Based on these characteristics, we can use six measures to characterize the shape of the jars in a manner that goes from more global measures of shape to more localized measures for a portion of the jar.

(1) The overall shape of the jar can be represented by the Total Height and the Belly Diameter variables—that is, by the shape of a rectangle with these two dimensions (see Figure 8.15 A). This rectangle rotated around a vertical axis generates the three-dimensional space within which the potter is working when fashioning other aspects of the shape of the jar.

(2) The Belly Diameter/Rim Diameter (B/R) ratio measures the geometry of the upper portion of the jar formed by a chord from the widest part of the belly to the rim in a two-dimensional cross section of the jar (see Figure 8.15 B). If $B/R > 1$, then the upper portion is convergent as one goes from the belly of the jar to the rim. If $B/R < 1$, then the upper portion is divergent; and if $B/R = 1$, the upper portion is parallel with no overall change in the diameter of the jar. The rate of convergence (or divergence) is due both to the magnitude of B/R and the Total Height/Belly Height ratio.

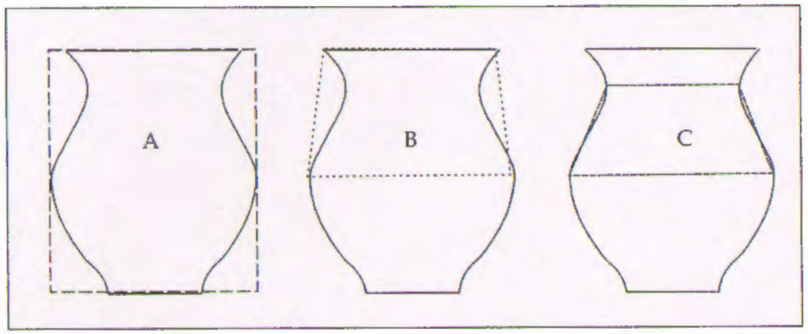
(3) The Total Height/Belly Height ratio identifies the relative location of the belly of the jar along the vertical dimension of the pot.

(4) The Belly Diameter/Base Diameter ratio is a similar measure for the geometry of the lower portion of the jar (not shown).

(5) The Belly Diameter/Neck Diameter ratio determines the local geometry for the portion of the pot going from the belly to the neck (see Figure 8.15 C) in conjunction with the Total Height/Neck Height ratio.

(6) The Total Height/Neck Height ratio identifies the relative location of the neck in the vertical dimension of the pot.

Figure 8.15: Three basic shape measures for pottery jars. (A) Overall shape represented by an enclosing rectangle. (B) Geometry of the upper portion of the jar measured by the Belly Diameter/Rim Diameter ratio and the relative location of the belly along the vertical dimension. (C) Geometry of the neck portion of the jar measured by the Belly Diameter/Neck Diameter ratio and the relative location of the neck between the belly and the rim

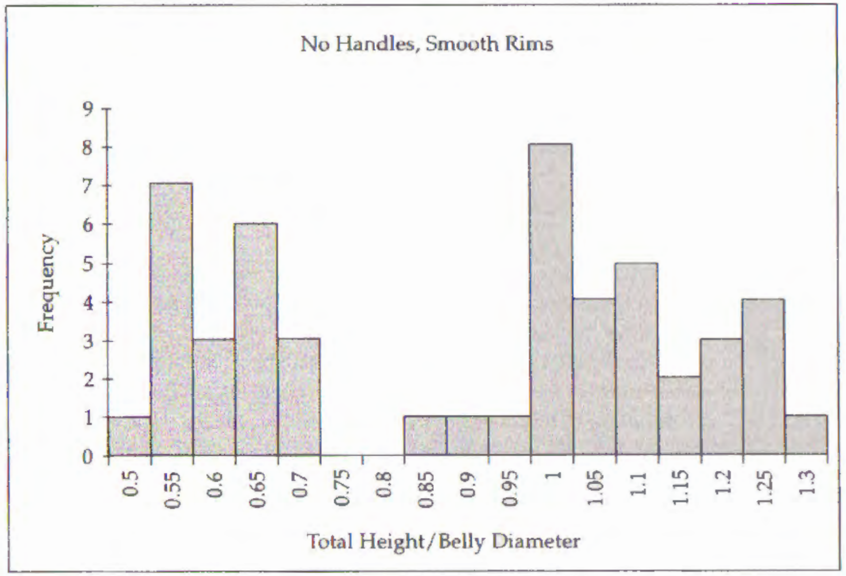


Other measures can be constructed if there are aspects of the shape that are found to have cultural saliency and are not measured by the above ratios, but these suffice for distinguishing shape differences among the Niederwil jars.

Global Shape: Belly Diameter and Total Height

The shape of a rectangle with dimensions given by the Belly Diameter and the Total Height can be measured with the ratio of these two variables. A histogram of Total Height/Belly Diameter is shown in Figure 8.16 and has an obvious bimodal distribution. The left mode corresponds to Squat Shape jars and the right mode corresponds to Urn Shape jars. The lack of unimodality of the histograms for the modes indicates that each is composed of heterogeneous data and so further subdivision of the jars will be needed.

Figure 8.16: Histogram of the Total Height/Belly Diameter ratio



A scattergram plot of the variables making up the shape ratio is given in Figure 8.17. The jars separate into the two groups corresponding to the two modes for the shape ratio histogram. The jars with indented rims have been included to show the relationship between the shape of the indented rim jars and the other jars without handles. These jars have the same overall shape as the Urn Shape jars. Both the Urn Shape jars and the Squat Jars show two additional main clusters in the scattergram plot.

Each group of jars follows a linear distribution with a constant shape value (see Figure 8.18). For the Urn Shape jars, and including the Indented Rim jars, the correlation between the two variables is $r = 0.96$. The null hypothesis, H_0: y-intercept = 0, cannot be rejected at the $\alpha = 0.05$ significance level ($n = 36$, $t = 1.76$, $p = 0.087$); hence, the jars have a constant

Figure 8.17: Scattergram plot of Total Height versus Belly Diameter

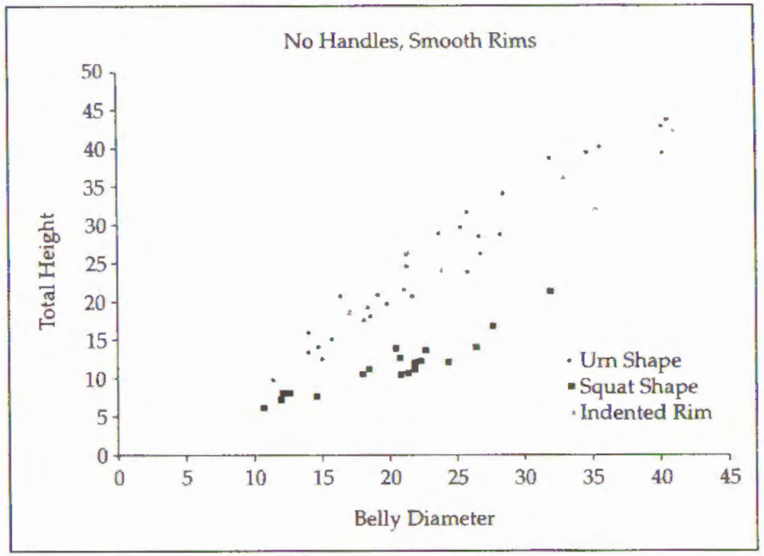
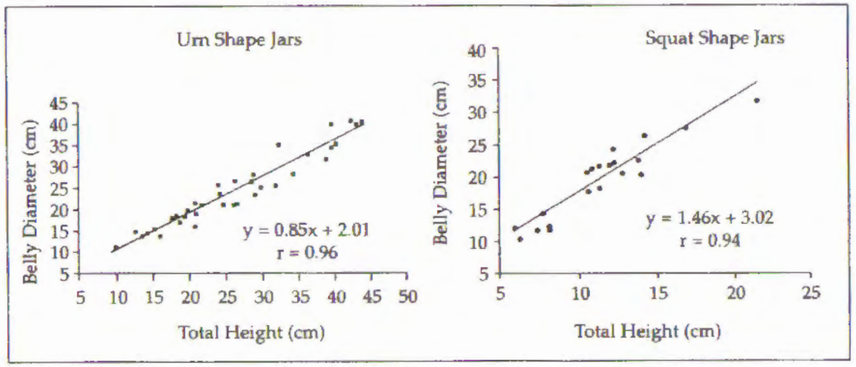


Figure 8.18: Left diagram: scattergram plot of Total Height versus Belly Diameter for Urn Shape jars. Right diagram: scattergram plot of Total Height versus Belly Diameter for Squat Shape jars



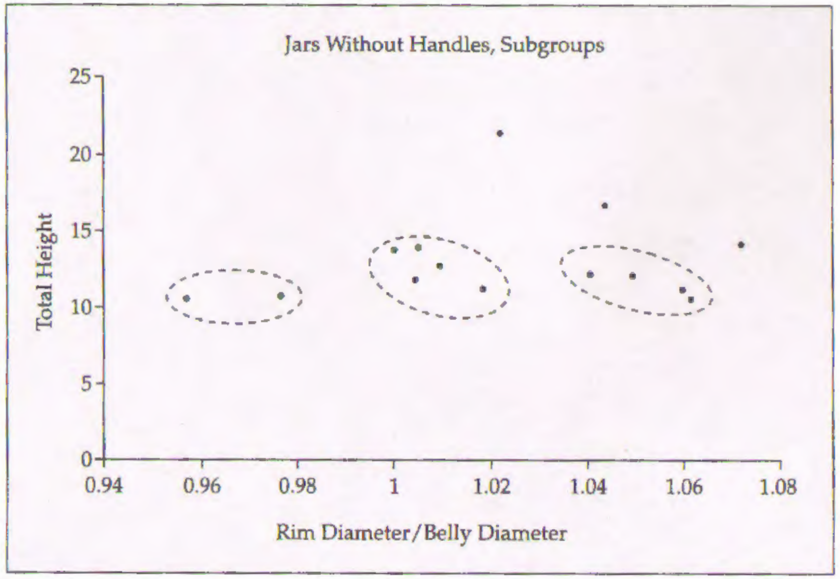
shape over the range of values for Total Height and Belly Diameter.[10] We obtain similar results for the Squat Shape jars. For these jars, $r = 0.94$ and the null hypothesis, H_0: y-intercept = 0, cannot be rejected at the $\alpha = 0.05$ significance level ($n = 20$, $t = 1.99$, $p = 0.062$). These jars also have a constant shape. We divide the data set into two subgroups, Squat Shape and Urn Shape, according to the two modes shown in Figure 8.17 but excluding the Indented Rim jars.

Squat Shape Jars

We can also see from Figure 8.18 (right diagram) and without any further analysis that the group of six points in the lower left of the figure is distinct, in terms of size, from the other Squat Shape jars. Hence, the Squat Shape can be divided into two subgroups based on the distance of a data point from the origin in the scatterplot in Figure 8.18. This yields two subgroups, Small Squat Shape jars and Large Squat Shape jars.

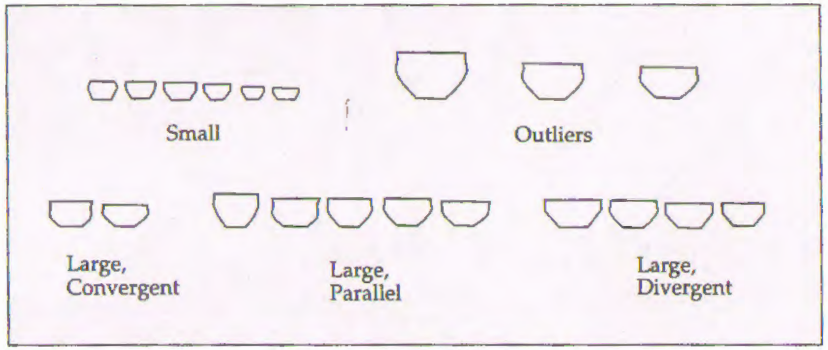
The jars in the Large group appear to have shape differences based on the Rim Diameter/Belly Diameter ratio in conjunction with height of the jar. A scattergram plot of this ratio versus Total Height shows three groups of jars differing with regard to the Rim Diameter/Belly Diameter ratio: (1) ratio < 1 (converging); (2) ratio ~ 1 (parallel); and (3) ratio > 1 (diverging). In addition, three jars are outside these groups and are distinguished by a larger value for Total Height than is the case for the other jars near them in a scattergram plot of the ratio Rim Diameter/Belly Diameter versus Total Height (see Figure 8.19, groups identified with dashed ellipses). We will label the three groups Large Convergent, Large Parallel, and Large Divergent, respectively, and the three remaining jars, Outliers. The group of six jars distinguished in Figure 8.18 (right diagram) will be labeled Small. The outlines for the jars in each of the groups we

Figure 8.19: Scattergram plot of Rim Diameter/Belly Diameter ratio versus Total Height



have distinguished so far are shown in Figure 8.20. Each of the groups has what appears to be continuous variation in size within a group.

Figure 8.20: Outlines of groupings determined for Squat Shape jars

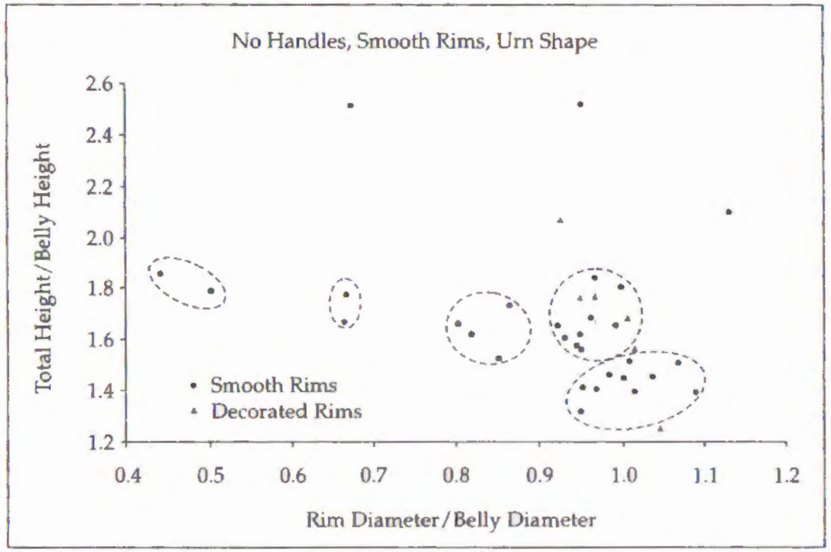


Urn Shape Jars, Smooth Rims

No single variable, nor pair of variables in the form of a shape ratio, shows the kind of modality that would be needed to account for the non-unimodal histogram for the Urn Shape jars. Visual inspection of the Urn Shape jars suggests that shape differences among them are based on both the shape measured by the Rim Diameter/Belly Diameter (R/B) ratio and the relative vertical location of the Belly Diameter on the jar measured by the Total Height/Belly Height (T/B) ratio. A scattergram plot of these two ratios separates the Urn Shape jars with smooth rims into five clusters and three outliers (see Figure 8.21). The downward trend in T/B with increasing values for R/B may reflect the fact that the smaller the latter ratio, the lower the location for the widest part of the belly on the jar. The three groups on the left with a convergent value for the B/R ratio will be labeled (going from left to right) Convergent A, B and C. The two larger groups on the right side of Figure 8.21 have similar values for the R/B ratio but differ in the relative location of the widest part of the belly of the jar and in the angle of convergence when going from the widest part of the belly to the rim. The upper of these two groups has a more rounded belly and the other group a flatter belly, so we will label these the Round Belly and Flat Belly types, respectively. The three outliers are jars with distinctive shapes, all with the belly portion located much lower on the jar than for any of the other jars in this subgroup.

The Indented Rim jars are also plotted in Figure 8.21 as gray triangles. Three of the Indented Rim jars easily fit with the Round Belly group and another one with the Flat Belly group. A fifth Indented Rim is close

Figure 8.21: Scattergram plot of Rim Diameter/Belly Diameter versus Total Height/Belly Height for Urn Shape jars



to the Flat Belly group and the sixth Indented Rim jar is an outlier. We next compare the sizes of the jars comprising the Round Belly and the Flat Belly groups.

Size of Flat Belly and Round Belly Jars

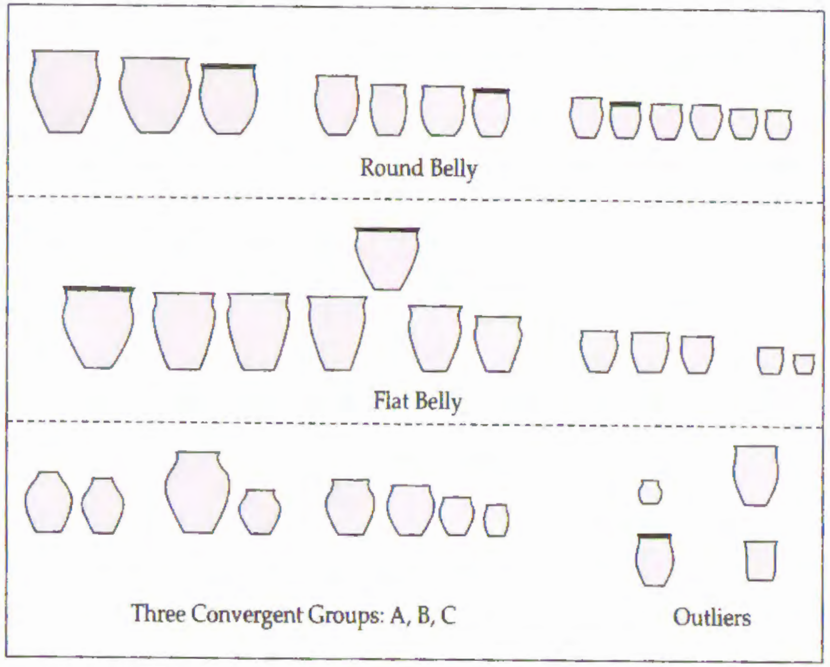
Both the Flat Belly and Round Belly jars can be subdivided into three size categories. The size category differences are shown using the height of the jars placed in order from tallest to shortest (see Figure 8.22). The mean, standard error, sample size, t value (for comparing comparable Round Belly jar size categories with Flat Belly jar size categories) and p value for the t-value are given in Table 8.3. The two groups of large jars do not have a significant difference in their respective mean vessel height measures. The two groups of medium-sized jars do have a significant difference and the two groups of small jars are on the boundary for significance at the 0.05 level. The small sample sizes imply that the t-test comparison of means for each of the three size categories, however, is not a powerful test. When we take this into consideration, the consistent pattern of the Round Belly jars having a larger mean vessel height than the comparable Flat Belly jars suggests that the difference in size between the two kinds of vessels (Round Belly and Flat Belly) may reflect different concepts of size appropriate for these two classes of jars.

We can also compare the Urn Shape jars with rim indentations to the groups of jars shown in Figure 8.22. The top row displays the Round Belly jars arranged from tallest to shortest with the placement of the Indented Rim jars within this group of jars. The middle row does the same for the Flat Belly jars. For the Round Belly jars, the Indented Rim jars have shapes matching the shape of the jars in the group to which they are assigned, which suggests that these Indented Rim jars were formed by adding rim decoration to what otherwise would have been a smooth rim jar. There is no evidence that a distinctive shape of Round Belly jar was produced when the rim was indented.

Table 8.3: Comparison of Size Groups for Round Belly versus Flat Belly

Type Class	Mean	Standard Error	n	t	p
Round, Large	41.25	1.75	2	1.31	0.25
Round, Medium	26.63	1.23	3	4.18	0.014
Round, Small	17.2	1.18	5	2.52	0.05
Flat, Large	36.28	2.19	5		
Flat, Medium	20.6	0.7	3		
Flat, Small	11.7	8	2		

Figure 8.22: Jars arranged from tallest to shortest. Round and Flat Belly jars are divisible into three distinct size groups. The Convergent B group can be divided into two size groups. The outliers include one rim decorated jar



Outliers

Two of the four outliers fit within the Urn Shape jars but have shape distinctions within this broad shape class that do not match any of the other Urn Shape jars. In terms of the type-variety distinction, these would be instances of varieties within the Urn Shape type. The other two outliers appear to have distinctive shapes unlike any of the other jars and hence are "true" outliers (see bottom row, Figure 8.22).

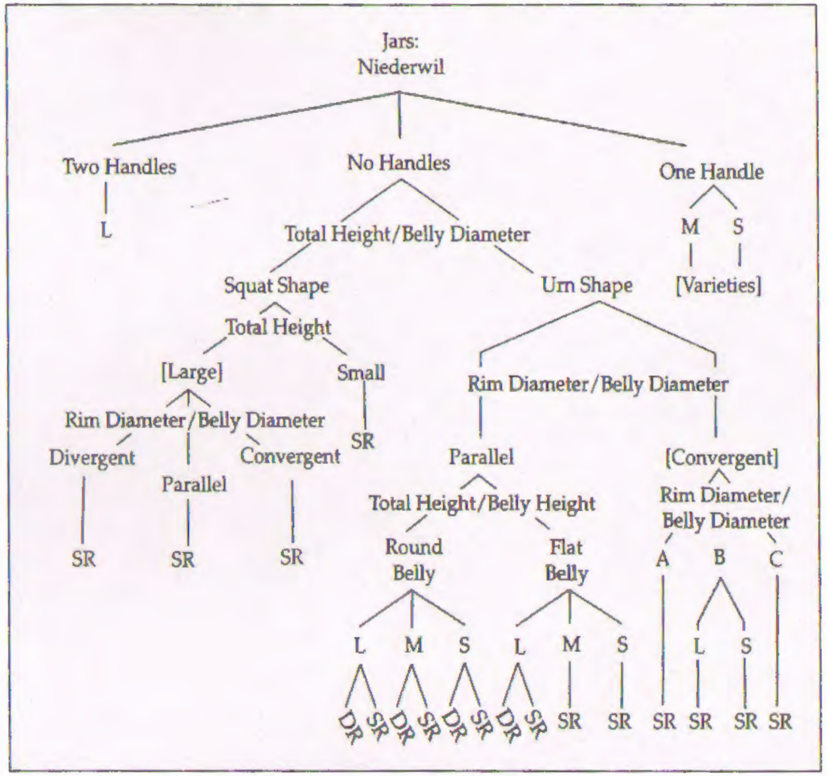
Taxonomic Structure

In Figure 8.23 we summarize the taxonomic structure for the classes that we have discovered. The first division is based on topological criteria—here, the number of handles for a jar. The one-handled jars are medium or small in size and composed of a variety of shapes (see Figure 5.4). There is a single, large two-handled jar. The second division is based on the shape of the jars. The names in square brackets indicate a class that can be subdivided into subclasses. The variable used for the subdivision of a class is shown immediately below the class being subdivided. The letters L, M, and S refer to large, medium, and small size classes, though the criteria for the classes need not be the same for different branches—for example, the size distinctions made between the Round Belly and Flat Belly jars. DR and SR refer to decorated (indented) and smooth rims.

It appears that the jars were made with two basic shapes: Squat Shape and Urn Shape. Each of these two shapes is further subdivided based on the shape of the upper portion of the jar within the two basic shapes. Size differences within a shape class occur for virtually every shape class that is distinguished, suggesting that there may have been differential use of the jars according to the size of a jar within a shape class.

The typology for these jars is a taxonomy (see Figure 8.23). It can, however, be embedded within a paradigmatic classification using the following six dimensions and attributes (in parentheses): (1) number of handles (0, 1, 2); (2) rim decoration (Decorated, Not Decorated); (3) overall shape (Squat, Urn); (4) shape of upper part of jar (Convergent, Parallel, Divergent); (5) shape of belly (Round, Flat, A, B, C); and (6) size of jar (Small, Medium, Large). The last set of attributes—small, medium, and large—do not always refer to the same metric distinctions since small versus large for the squat jars is based on a different set of quantitative boundaries than that for the round belly jars. The paradigmatic classification based on these six dimensions would have $3 \times 2 \times 2 \times 3 \times 5 \times 3 = 540$ different cells (ignoring the two sets of size differences), and 523 of these cells would be empty; hence, the paradigmatic classification is technically accurate but has no emic validity. Problems with making a paradigmatic classification

Figure 8.23: Taxonomic structure for the typology determined for the Niederwil pottery jars (outliers are not included)



for these pots also lies in the assumption that each dimension has attribute values that potentially may apply to any jar. However, a distinction such as Round Belly versus Flat Belly, for example, only makes sense for the Urn Shape jars.

Summary

These two examples illustrate, for both lithics and pottery, the steps involved in constructing a culturally salient artifact taxonomy. Qualitative differences based on culturally salient dimensions are used to subdivide the collection of artifacts into distinct groups prior to the analysis of quantitative dimensions due to the double bind problem that arises when forming types with quantitative dimensions. The double bind problem does not arise with qualitative dimensions since patterning based on qualitative distinctions can be observed on individual artifacts.

The asymmetry between first making qualitative divisions and then quantitative divisions versus first making quantitative divisions and then qualitative divisions provides the logical rational for beginning with qualitative dimensions and only then considering quantitative dimensions. The asymmetry arises since quantitative distinctions need not apply unambiguously to all of the qualitative differences since quantitative patterning is aggregate specific, but qualitative distinctions apply unambiguously to all quantitative groupings since qualitative patterning is observable on individual artifacts.

Both examples illustrate that the methods presented here go far beyond what might be identified through an intuitive gestalt approach. Though the concave/convex distinction for the projectile points does not require statistical analysis for the patterning to be discovered, the narrow/wide distinction among the concave projective points could easily be missed without the statistical analysis. The fact that the short triangular points have a length/width/angle structure consistent with resharpening has not previously been identified in sites with this kind of projectile points. Similar comments apply to the Niederwil pots.

The subdividing procedure presented in this chapter has also been applied to Scottsbluff projectile points (Read 1982) and to utilized flakes (Read and Russell 1996). The latter application found subgroups as clear cut as the subdivisions found using the methods discussed in this chapter. The utilized flake analysis highlights the fact that these methods make it possible to objectively construct a typology even in the absence of formal tool types, but with the difference that the utilized flake types do not arise from conceptualized forms but from schemas for deciding whether a flake can be used effectively for the task at hand. Schemata can be individually learned through experience (that is one learns the relationship between the geometry of a flake, the location of an edge on the flake, and how the flake will be held for doing the intended action), in which case the typology would not be culturally salient in the sense of being based on a shared conceptual system for the distinctions among the flake types.

Frequency counts are relevant to determining quantitative types through displaying patterning in a frequency distribution or a histogram rather than through statistical measures of association between variables. Whether two variables are associated only affects the shape of the joint distribution for the pair of variables, not whether the joint distribution consists of distinct clusters of data points. The latter is the basis for making subdivisions with quantitative variables. The former relates to the shape of the artifacts in question. Frequency counts, however, may be used to determine whether types have similar frequency of usage, hence form usage types, the topic of the next chapter.

9 Patterning Based on Type Frequency Counts

Taxonomy versus Paradigm Structures

The typological structure that we developed for the Niederwil pottery collection makes it evident that a taxonomic—and not a paradigmatic—typology is the likely outcome when forming a typology based on a data set composed of not well-defined variables and not well-defined data. For data of this kind, the typological task is geared toward determining a subset of the variables relevant to forming categories on the basis of the data brought forward for analysis. There is no reason to assume that types can be defined using a fixed set of variables applied equally to all entities in the data set. More likely, we will find that only some of the measures are relevant to defining types that make up just a portion of the data set.

This is not to say that paradigmatic classifications are irrelevant. They are relevant, but not for data sets composed of not well-defined variables and data. Paradigmatic classifications will arise when we have a collection of artifacts made in an exhaustive manner, in the sense that decisions had to be made by the artisan about the value to be expressed on an artifact for each variable in a set of variables, and the same decision process occurred with each artifact that was produced. The kind of classifications typically made of pottery objects and based on qualitative or bifurcate quantitative dimensions of a pottery object such as kind of temper, surface treatment of the clay, use of decoration, and so on, lend themselves to a paradigmatic classification.

The method of pottery manufacture—in the *chaîne opératoire* notion of artifact production—can be viewed as a sequence of steps, each of which requires a decision with respect to the value to be embedded on the object at that step, but each step can potentially be done independently. Thus, the artisan must decide whether to temper the clay, what surface

treatment will be used, whether any kind of decoration will be applied to the pottery object, and so on. While the order in which these dimensions are addressed while making a pot may be fixed (or nearly fixed), the dimensions can conceptually be considered in any order.

Types and Attribute Value Association

Though the artisan can mentally decide whether to decorate before deciding on temper, the value assigned to one dimension may influence the value assigned to another dimension, and so the value on one dimension is associated with the value on another dimension. For example, it is not likely that the artisan will apply painted decoration to a pot whose surface has not been smoothed or polished since the surface needs to be smooth in order for the decoration to have the quality desired by the artisan. Or it may simply be that, for whatever reason, an attribute on one dimension is never combined with a particular attribute on another dimension—such as the attribute, indented rims, does not occur with jars having handles among the Niederwil jars analyzed in the previous chapter.

For either a taxonomic or a paradigmatic classification, we can have association (or lack of association) between an attribute value on one dimension and an attribute value on another dimension and it is the pattern of association among attribute values such as "triangular shape, concave base, narrow" for the 4VEN39 projectile points that provides a type definition. Association, in this sense, is patterning that can be observed on individual artifacts rather than patterning "in the aggregate" and is the basis for most pottery typologies.

Types and Group Sorting by a Similarity Measure

We can also infer a type by first sorting artifacts into groups based on a similarity measure. If the groups that are found show "internal cohesion and external isolation," then we could conclude that each group consists of artifacts of the same type. For example, we determined that the triangular points from 4VEN39 could be divided into two groups based on a measure of the "base height"—negative if the base is indented and positive if the base extends outward. One of these groups could be subdivided into two additional groups based on the width of the points and we can completely characterize the inferred classes—when the data for each of the groups have a joint normal distribution—by a population mean, standard deviation, and covariance estimated by the

sample mean, standard deviation, and covariance measured over the artifacts in hand.

In this example, we also characterized the points by reducing the ratio scale variables to nominal variables on the basis of the nonoverlapping modes in a frequency distribution for the dimensions of concern. This led us to first divide the points into concave versus convex points and then divide the concave points into narrow versus wide points. Hence, we can either characterize the inferred classes using parameters that characterize the shape of the distribution of data points in the space determined by the ratio scale measurements made over the projectile points, or we can characterize the classes using nominal variables whose values represent the nonoverlapping modes used to form the groups of projectile points.

Reducing the ratio scale variables to nominal scale variables carries with it the assumption that variability in the measured values within a group corresponding to a class primarily—if not entirely—represents incidental variation introduced during the making of (in this example) a projectile point, even though the artisan had a target base indentation or target width in mind when making the point. Characterizing the projectile point class with the nominal reduction of a ratio scale variable assumes that a class defined by using attribute values from a nominalized quantitative dimension is closer to emic concepts regarding the projectile points than a class definition based on parameter values that characterize the joint distribution for the ratio scale variable. This assumption will be justified when a bimodal distribution for a continuous quantitative variable arises due to artisans choosing between two different ways to make an artifact.[1]

Object Clustering versus Attribute Association

The two ways to characterize the class definitions—parameter values that characterize a joint normal distribution versus a nominalized quantitative variable—exemplify the distinction that has been made between *object clustering* (grouping objects on the basis of similarity) and *attribute clustering* (determining sets of attributes whose co-occurrence is "nonrandom" and presumably intentional). For the projectile points analyzed in the previous chapter, we can either define a type through object similarity (where two objects are similar if they belong to the same joint normal distribution) or by attribute combinations (such as concave base + narrow width points, where the attributes pairs concave/convex and narrow/wide are based on the bimodality of the base height and the base width variables, respectively). The two ways of forming class definitions lead to the same types. They differ mainly in the amount of

information from a frequency distribution that is carried forward as part of the type definition. A type definition based on the parameters that characterize a frequency distribution carries with it more information about properties of the distribution than does a definition based on the attributes that are the values for a nominal scale inferred from the characteristics of the frequency distribution. The parameters of the frequency distribution, for example, cannot be recovered from a nominal scale inferred from the shape of a frequency distribution.

Attribute Association (Co-occurrence) versus Variable Association (Frequency Counts)

If this were all that is involved with attribute association, then there would be little controversy over whether type definitions are based on object clustering or attribute association. The matter was unnecessarily made more complicated, as discussed in Chapter 4, when a different notion of attribute association based on variable association was introduced. To see the difficulty, instead of simply observing which attribute combinations occur for the projectile points, consider what happens when we attempt to use variable association between nominal variables in type definitions.

For the 4VEN39 projectile points and using the two nominal variables Base Shape (concave, convex) and Width (narrow, wide), we have a 2 × 2 contingency table (Table 9.1), where we must introduce the attribute other in order to apply the Width nominal variable to the convex points. It is evident from this table that the values for the variable Width are not independent of the values for the variable Base Shape, and so these two variables are associated and there is nonrandom association between the attributes for the variable Width and the attributes for the variable Base Shape. From these data, we could conclude that there are three types: concave-narrow, concave-wide, and convex-other.

Thus, it would appear that we could begin the analysis by forming a table like this and determining if the variables making up the table are associated—and if so, identifying the types = attribute combinations represented in the table. In this case, we still arrive at the same three types as

Table 9.1: Two-Way Contingency Table for Projectile Points

		Base Shape	
		Concave	Convex
Width	Narrow	31	0
	Wide	33	0
	Other	0	64

we found before, but the reason for so doing has to do with the pattern of 0's in the table. Each row and each column consists of a single nonzero value, thereby providing us with a table that has a straightforward and unambiguous way to relate variable associations and attribute combinations.

Frequency Counts versus Type Definition

Now consider a more common case where we have a contingency table without (or with very few) zeros. We will use the hypothetical pottery example introduced earlier where we considered two nominal variables, each with two attributes, and further stipulated that the potters belong to four clans and each clan made pottery using a single attribute combination (as indicated by listing a clan in each cell in Table 9.2). From the perspective of each clan, we have four types of pottery, one type made by each clan.

Table 9.2: Change in Frequency Counts Through Time

		Time Period 1		Time Period 2	
		Variable 1		Variable 1	
		Attribute A	Attribute B	Attribute A	Attribute B
Variable 2	Attribute I	50 (Clan 1)	50 (Clan 2)	400 (Clan) 1	50 (Clan) 2
	Attribute II	50 (Clan) 3	50 (Clan) 4	200 (Clan) 3	50 (Clan) 4

Suppose in addition we have pottery from two time periods. During the first time period, all four clans have the same population size and potters make pottery at the same rate, so all four cells in the contingency table have the same frequency counts (see Table 9.2: Time Period 1). In the second time period, two clans have become much larger than the other two clans and so the former make more pottery than the latter (see Table 9.2: Period 2). From a variable association viewpoint, the two variables are independent in the first time period but are associated in the second time period; hence, we would reach different conclusions about pottery types in each of these two time periods based on variable association. In the first time period, there are no nonrandom attribute combinations based on variable association, but in the second time period there are nonrandom attribute associations. Yet nothing has changed except the quantity of pottery made by two of the clans.

For data like these, Cowgill (1982)—following Spaulding's (1977) argument about using variable association to determine class definitions—argued that we should consider the two attribute combinations that occur

more frequently in Table 9.2: Period 2 as indicators of types and the other two attribute combinations as "atypical or transitional objects" (p. 41) and that the data in Table 9.2: Period 1, from the viewpoint of defining types, are "ambiguous and less satisfactory" (p. 41). This does not make sense. The types are not made more or less clear-cut by demographic changes in the clans that affect the quantity of pottery that is produced. The types are clear-cut and the same for both tables: each cell in the contingency table is a type. What differs between the two tables is the frequency of occurrence of types, not what is a type.

Attribute Value Combinations and Types

Spaulding erred by confounding frequency counts and variable association with type definitions. An attribute combination does not become a type only when it is made relatively more frequently, as is implicitly assumed when one links non-random *attribute combinations* with *variable association* for nominal variables. Cowgill (1982) simply extended and compounded the error in his attempt to set up a distinction between object clustering and attribute association as the basis for type definitions when he concluded, "[F] or pairs of nominal variables with some values much more frequent than others, the variable-association approach is distinctly preferable" (p. 47).

The arguments of both Spaulding and Cowgill have needlessly confounded the information provided in frequency counts for attribute combinations with type definitions and failed to recognize that the frequency counts provide information about rates of type production, which relates to type *usage* and not type *definition*. Objects that are used infrequently are no less types than objects that are used frequently, and changing the frequency through time with which objects are used does not change what constitutes a type.

Frequency Counts and Usage Types

The frequency counts provide a different kind of information than what is used to define a type in the first place. The frequency counts provide direct information on rates of pottery type production and this may be due to relative usage of types in various activities; hence, the frequency counts provide information on what we defined as a *usage type* in the introduction: a combination of types whose frequency of usage is similar due to each of the types being used as part of the same activity. Data such as those shown in Table 9.2: Time Period 1, could be due to the four types each being used in a single activity with equal frequency. That each type is used equally frequently does not diminish its status as a type.

Similarly, in Table 9.1 we determined that there are three types not because of the magnitude of the frequency counts, but because the frequency counts indicate which attribute combinations occurred on at least one artifact and which attribute combinations did not occur. This implies, for the purpose of type definition based on a paradigmatic representation of the variables in the form of a contingency table, that we can simply reduce the frequency counts to 1's or 0's and the types correspond to the 1's in the contingency table. In other words, the occurrence of an artifact with a particular attribute combination suffices to define that combination as a type.[2] It is a type since nominal variables can express a pattern on an individual object that does not require looking for patterning in the aggregate. A sand tempered bowl with decoration is a type, for example, not because "bowl" is an attribute that occurs with the attribute "sand temper" and with the attribute "decorated" in a nonrandom manner in some population of pottery objects (as inferred from the pattern of variable association), but because an artisan used clay with sand temper and decorated the bowl that he or she made. The frequency count of sand tempered, decorated bowls in a collection of pottery objects reflects the frequency of use (or demand) for this particular type of pottery, not whether sand tempered, decorated bowl is a type. The artisan might only make a few sand tempered bowls if sand tempered, decorated bowls are only used once a year in a ritual; it is no less a type merely by virtue of the fact that this combination of attributes on pottery objects does not occur frequently.

The frequency counts displayed in a paradigmatic classification thus provide information above and beyond what is needed for identifying types. The additional information has to do with the relative frequency with which one type occurs in comparison to other types. We now consider a sequence of hypotheses about these frequency counts and a method for determining what combinations of types in the paradigmatic classification should be grouped together to form a usage type.

2 × 2 Contingency Table Patterns and Usage Types

We will make use of measures of association based on a 2 × 2 contingency table, but only in a limited sense as will be seen below. We will assume, for simplicity of illustration, that we have data from an entire population so that the frequency counts are the actual counts over a population and we can express patterns by referring to equality or inequality of frequency counts. We will also assume that the data in a single cell in the contingency table are the consequence of a single process or event and are not data summed over several processes or events.[3]

Pattern 1: All cells have equal frequencies—$n_{11} = n_{12} = n_{21} = n_{22}$. This pattern would arise if all four types were used equally in whatever activities or events are relevant to these types. Hence, we have a single usage type composed of the four types in the paradigmatic classification.

Pattern 2: Three cells have equal frequencies and the fourth cell has a different frequency—for example, $n_{11} = n_{12} = n_{21} \neq n_{22}$. This pattern would arise if three types are used equally in a single kind of activity or event and the remaining type is used separately in another event. Hence, we have a single usage type composed of the three types with the same frequency counts and a single type.

Pattern 3: Two cells have the same frequency counts and the other two cells also have the same frequency counts, but the frequency counts differ between the two pairs of cells—for example, $n_{11} = n_{12} \neq n_{21} = n_{22}$. Here we would posit two usage types, each based on a pair of types that have the same frequency counts.

Pattern 4: Two cells have the same frequency counts and the other two cells each have a unique frequency count—for example, $n_{11} = n_{21} \neq n_{12} \neq n_{22}$. For this pattern, we would form a usage type based on the two cells with the same frequency counts and two separate types.

Pattern 5: All four cells have different frequency counts—$n_{11} \neq n_{21} \neq n_{12} \neq n_{22}$. For this pattern, the frequency counts corroborate treating each cell as a separate type.

For Patterns 1 and 3, the two variables making up the 2 × 2 table are statistically independent, whereas for Patterns 2, 4, and 5 the cell frequency counts imply that the two variables are not statistically independent. Statistically independent variables are characterized by the observed frequency counts matching the expected frequency counts in each cell using the calculation $e_{ij} = (n_{i.}/n_{..})(n_{.j}/n_{..})n_{..} = (n_{i.} \times n_{.j})/n_{..}$, where e_{ij} is the expected frequency count for the cell in the ith row and jth column, $n_{i.}$ is the sum of the frequencies in the ith row, $n_{.j}$ is the sum of the frequencies in the jth column and $n_{..}$ is the sum of all cell frequencies. If the variables are not independent, then we can first determine which cell has the greatest deviation from the expected value for that cell based on the magnitude of $(n_{ij}-e_{ij})^2/e_{ij}$—the amount that cell contributes to a chi-square value for the contingency table. Then we can measure the extent to which that cell is either over- or under-represented by determining the value $e_{ij}*$ such that when n_{ij} is replaced by $e_{ij}*$ in the modified contingency table, the observed and expected cell values are identical.

Computation of Cell Interaction Effects

The value for $e_{ij}*$ will not be e_{ij} based on the original table since simply replacing n_{ij} by e_{ij} will lead to new expected values for each of the cells in the contingency table. Instead, $e_{ij}* = (n_{i.}n_{.j} - n_{ij}(n_{i.} + n_{.j} - n_{ij}))/(n_{..} + n_{ij} - n_{i.}\, n_{.j})$ (Read 1989a). The difference $e_{ij}* - n_{ij}$ measures the extent to which the type corresponding to n_{ij} is under-represented in the contingency table if $e_{ij}* - n_{ij} > 0$, or over-represented if $e_{ij}* - n_{ij} < 0$.

When using sample—rather than population,—data, we use a statistical test based on a chi-square distribution to determine if the variables are independent. For an $m \times n$ table, the χ^2 value is estimated by the computation $X^2 = \Sigma(n_{ij}-e_{ij})^2/e_{ij}$, where the symbol Σ means that we take the sum of all the terms of the form, $(n_{ij}-e_{ij})^2/e_{ij}$, one term for each cell in the table. The χ^2 computation has degrees of freedom (df) = $(m-1)(n-1)$ and the computed value of χ^2 is compared to a standard table of χ^2 values with df = $(m-1)(n-1)$ to determine if the computed value, X^2, is consistent with the null hypothesis that the variables are statistically independent. If we find that the variables are not consistent with the null hypothesis of independent variables, then we may compute $e_{ij}*$ to determine the amount by which one of the types is over- or under-represented and hence a basis for the nonindependence of the variables.[4]

Iterative Modification of Cell Values

The calculation $e_{ij}* = (n_{i.}n_{.j} - n_{ij}(n_{i.} + n_{.j} - n_{ij}))/(n_{..} + n_{ij} - n_{i.}\, n_{.j})$ applies to any $m \times n$ contingency table and can be applied iteratively to cells in the contingency table until we arrive at a table in which observed and expected values agree for all cells. In an $m \times n$ table, once we have modified one cell and changed its frequency count to $e_{ij}*$ (and allowing for the frequency count to be a fractional value if need be), we can then repeat the procedure on the modified table if there any cells in the modified table where the expected and the observed values do not agree (for population data) or are statistically different (for sample data). However, we may then find that the cell with value $e_{ij}*$ no longer has an expected value equal to $e_{ij}*$ due to the change in the value of another cell. Hence, we need to recompute the value for the previous cell that was modified and then determine if any other subsequently modified cell also needs to be changed. We continue in this manner until we converge on cell values that statistically match the expected values for these cells.[5]

At each step in the modification process, we lose one degree of freedom when the original value for a cell has been replaced by a modified value. The maximum number of cells that may need to be modified to arrive at a table in which $e_{ij} = n_{ij}$ is given by the degrees of freedom for the contingency table. For a 2 × 2 table, df = 1; hence, we only need to modify one cell to arrive at a modified table in which $e_{ij} = n_{ij}$. For an $m \times n$ table, we may need to modify up to $(m-1)(n-1)$ cells. For an $m \times n$ table, the process of modifying cells may converge to a nonsignificant chi-square

value before $(m-1)(n-1)$ cells have been changed. The set of modified cells can be viewed as a hypothesized set of types whose cell-by-cell under- or over-representation can account for why the variables were not independent in the unmodified data set. The modified cells (= types) can be compared to determine patterning either among the attributes for the types whose frequency counts have been modified, or for patterning in the change in their frequency counts (or percentage changes). In the latter case, we hypothesize that the types with the same percentage change in frequency counts form a usage type.

Hierarchical Interaction Models for Multiway Contingency Tables

We can extend the above results to contingency tables with more than two dimensions by first making explicit a sequence of statistical models that are part of determining the status of the two variables upon which an $m \times n$ contingency table is based. The sequence of models is as follows.

Model 1: All cells have the same frequency counts (for a population) or are statistically the same (for sample data). The expected cell values are given by $e_{ij} = n../mn$. The X^2 value for testing goodness-of-fit for Model 1 with sample data has df = $mn-1$.
Model 2: All cells in the same row have the same frequency counts (for a population) or are statistically the same (for sample data). The expected cell values are given by $e_{ij} = n_{i}./n$, where n is the number of columns. The X^2 value for testing goodness-of-fit for Model 2 with sample data has df = $m(n-1)$.
Model 3: All cells in the same column have the same frequency counts (for a population) or are statistically the same (for sample data). The expected cell values are given by $e_{ij} = n.j/m$, where m is the number of rows. The X^2 value for testing goodness-of-fit for Model 3 with sample data has df = $(m-1)n$.
Model 4: The variables are independent. The expected cell values are given by $e_{ij} = n_{i}. \times n._{j}/n..$. The X^2 value for testing goodness-of-fit for Model 4 with sample data has df = $(m-1)(n-1)$.
Model 5: The expected cell values are given by $e_{ij} = n_{ij}$ and df = 0. Model 5 is sometimes referred to as a saturated model since it must satisfy the goodness-of-fit criterion for contingency tables.

For a two-dimensional contingency table, one generally begins with Model 4 since one is often asking whether the variables are independent, but each of the first three models is also appropriate to be

tested for goodness-of-fit. Model 1 corresponds to the contingency table representing a single usage type composed of the types embedded in the $m \times n$ contingency table. Model 1 may also be viewed as indicating that both variables can be ignored in the sense that knowing the value for one or the other of the two variables does not affect the expected frequency counts in the table.

Models 2 and 3 are relevant to situations where the table is made up of a usage type based either on row cells (for Model 2) or on column cells (for Model 3) in the contingency table. Model 2 may also be viewed as indicating that the second variable can be ignored in the sense that knowing the values for the second variable does not affect the expected frequency counts in the table. A similar comment applies to Model 3 and the first variable.

We can represent the models using the following convention for notation. Let the variable be denoted by upper case letters at the beginning of the alphabet. For an $m \times n$ contingency table, we denote the two variables by A and B. We then specify a model by indicating, in brackets, which variables are included when computing the expected cell values for that model. Thus, if A is the row variable, then $[A]$ would indicate Model 2, $[B]$ would indicate Model 3, $[A, B]$ would indicate Model 4, and $[AB]$ would be the saturated model, Model 5. Model 1 will be indicated by I. The notation AB implies that the cell values represent interaction (or lack of independence) between the variables A and B.

This notation can be extended to tables with more than two variables. The added complication that is introduced when there are more than two variables is the possibility that the data in hand are due to the combined effects of more than one 2×2 contingency table. Thus, if we have three variables A, B, and C, we can specify a model according to the pattern of variables underlying the values in the contingency table. For example, we could have the model $[AB]$, which would imply that the original three-dimensional contingency table can be reduced to a two-dimensional contingency table based just on the variables A and B and the expected values would be computed using this two-dimensional table. These expected values would then be divided equally among the corresponding cells in the third dimension. Or we might have the model $[A, BC]$, which would imply that the observed values are due to a series of two-dimensional tables based on the variables B and C, one for each value of A. For the two-dimensional table corresponding to the ith value of the variable A, the total frequency count for that table would be the frequency count for the ith value of A over the complete data set. Thus, if the variable A has two attributes (a_1 and a_2) and there are n_1 objects in the data set with attribute a_1 and n_2 objects in the data set with attribute

a_2, then there will be two contingency tables, each based on the variables B and C. In the first of these two tables, the total count $n_{\cdot\cdot}$ will be equal to $n_{1\cdot}$ in the second table, the total count $n_{\cdot\cdot}$ will be equal to $n_{2\cdot}$. Finally, the expected values will be computed for each of these two tables separately and these will be the expected values for the cells in the full three-dimensional contingency table.

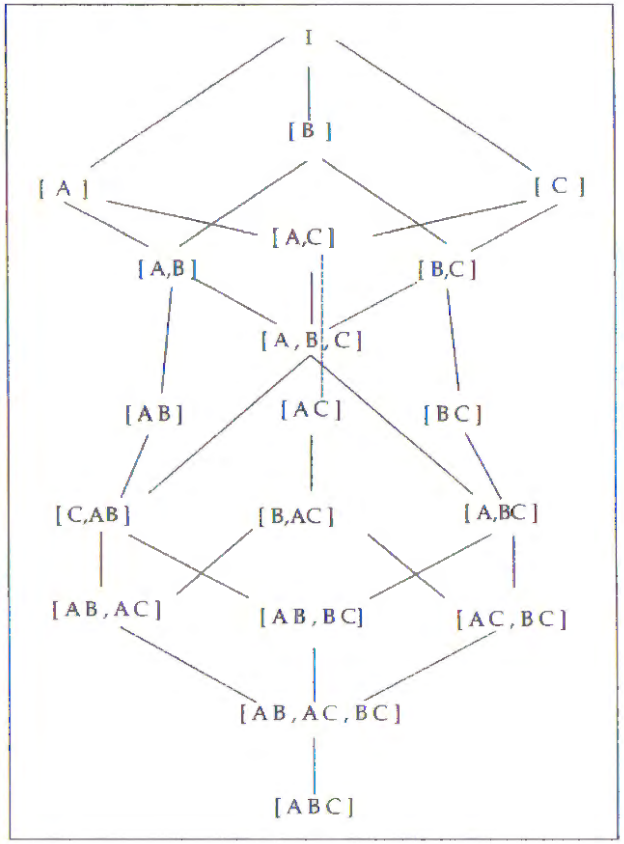
The number of possible models increases rapidly with the number of variables. With three variables, the possible models are I, A, B, C, [A, B], [A, C], [B, C], [A, B, C], AB, AC, BC, [A, BC], [B, AC], [C, AB], [AB, AC], [AB, BC], [AC, BC], [AB, AC, BC], and [ABC]. The model [ABC] is the saturated model and the model [A, B, C] corresponds to three variables that are mutually independent. The multiplicity of models underscores the problem with interpreting—when just focusing on independence of variables—what is meant by rejection of the null hypothesis that the variables are independent. If the data lead us to reject the null hypothesis of variable independence, then the pattern of variable interaction is still unspecified. Any of the models other than I, A, B, C, [A, B], [A, C], [B, C], or [A, B, C] in the above list are possibly valid if variable independence is rejected.

A method of analysis known as the log-linear analysis of categorical data (e.g., Agresti 1996) allows us to test each of the models to determine which model(s) for pattern(s) of variable interaction are consistent with the data brought forward for analysis. In place of a χ^2 value, the log-linear method computes a value known as the log-likelihood ratio (LLR) with degrees of freedom the same as for the χ^2 value. The log-likelihood ratio can then be tested for statistical significance in a manner analogous to testing a chi-square value for statistical significance.

We can display the interdependencies among the models in the manner shown in Figure 9.1. From Figure 9.1, a pathway of models can be tested sequentially by tracing downward along a path from more general to more specific models. If a model on a path is rejected, then we move to the next, more specific, model on the pathway and test whether the null hypothesis for that model should be accepted or rejected in terms of goodness-of-fit until we arrive at a model that is statistically valid for the data in hand; that is, the null hypothesis based on that model is not rejected. The main complication is that models on different pathways can be valid simultaneously. When more than one model is statistically valid, then a nonstatistical criterion (such as simplicity) may be used to select among the possible models if there are no data-related criteria for selecting among statistically valid models.

In addition to testing whether a model fits the data in hand, each step in the procedure of moving down a pathway can also be statistically tested for whether moving from one model to the next one in a pathway yields

Figure 9.1: Hierarchical relationships among all possible models with three variables *A*, *B* and *C*

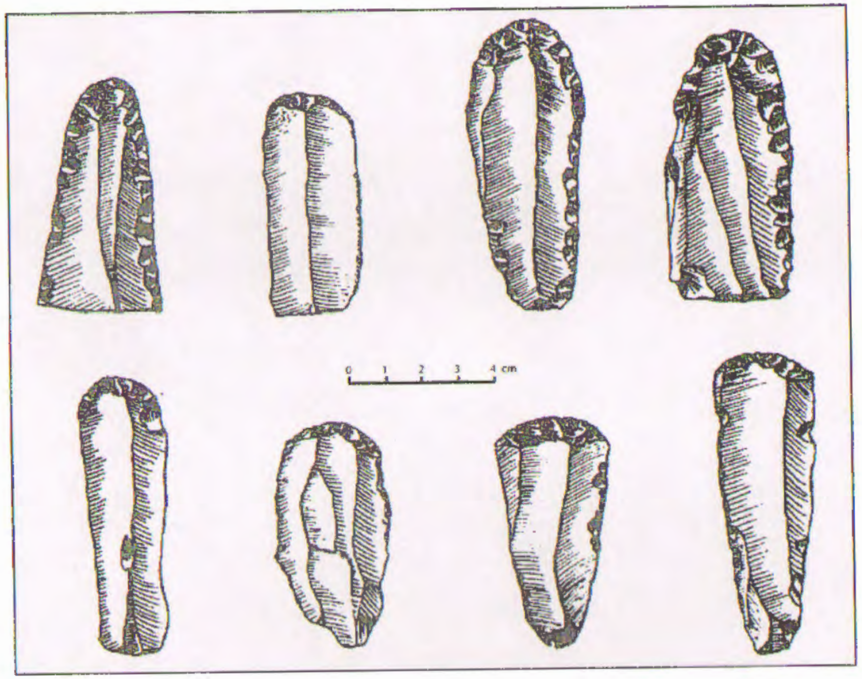


a statistically significant increase in the LLR goodness-of-fit measure by determining if the change in the LLR value when going from one model to another along a pathway is statistically significant, based on the change in degrees of freedom for the two models being compared. If the change in the LLR value is statistically significant (with the degrees of freedom for the change in the LLR value equal to the difference in the degrees of freedom for the two models that are being compared), then the model lower in the hierarchy fits the data significantly better. The test is independent of the fit of a model; it is possible that both models do not fit the data, but the second model has a significantly better fit than the first model. Thus, we can test both whether a posited model is valid and whether the shift from a more general model to this model along the same pathway yields a significant improvement in goodness-of-fit.

Log-Linear Analysis of Categorical Data

The log-linear method for analyzing categorical data was developed by statisticians to determine a pattern of variable association that would account for the observed values in a multiway contingency table. Dwight Read (1974b) made the first application of the log-linear method to archaeological data using data on Upper Paleolithic end-scrapers (see Figure 9.2) analyzed previously by James Sackett (Sackett 1966).[6] We will use these data for illustrating how to determine usage types in a multiway contingency table.

Figure 9.2: Aurignacian end-scrapers. Modified from Sackett 1966: Figure1



For his analysis, Sackett defined the following (etically) nominalized quantitative variables: (1) curvature of the retouched end of the end-scraper with three attributes, round, medium, and shallow; (2) whether the sides of the end-scraper are parallel or convergent; (3) whether the edge(s) of the end-scraper are retouched or unretouched; and (4) the width of the end-scrapers with two attributes, narrow and wide. The log-linear method for multiway contingency tables did not exist when Sackett did his analysis. In lieu of the log-linear method, he used two-way tables controlling for the values of a third variable.

Sackett's analysis had three drawbacks. First, he was forced to use a complicated and unsatisfactory search through many contingency tables to try to determine the pattern of association(s) among the four dimensions for the end-scraper data. Second, types defined as attribute combinations were to be inferred, following Spaulding's argument, from the pattern of association found among the four dimensions. And third, the quantitative dimensions were nominalized by criteria other than multimodality in a frequency distribution for each of the dimensions.

Though the third drawback makes any conclusions from these data based on the nominalized dimensions suspect, since it is possible that the divisions used to nominalize the quantitative variables crosscut multimodality in the frequency distributions for the quantitative variables, Read's analysis using log-linear methods nonetheless resulted in very clear patterning—thereby suggesting that the nominalization must in fact be close to modes in frequency distributions for at least some of the variables. In addition, conclusions drawn from analysis of the data provide an excellent example for demonstrating the usefulness of the log-linear method as a way to analyze a multidimensional paradigmatic classification for usage types.

The second drawback negates Sackett's analysis since (as discussed above) it confounded the notion of a type based on attribute combinations with the way in which the types defined using attribute combinations may be combined to form a usage type based on the pattern for the frequency counts in a multiway contingency table. For this reason, Read (1974b) introduced a method for examining the frequency counts in the contingency tables—corresponding to a model that fits the data—as a way to determine what type, or combination of types, would account for deviation in the frequency counts from the expected frequency counts in a table with independent variables. Read then used the results of this analysis to determine what usage types are embedded in the data based on frequency counts.

Method for Identifying Cells Accounting for Nonindependent Variables

Step 1: Determine an Interaction Model for a Multiway Contingency Table

The frequency counts for the end-scrapers from the Paleolithic site, Castanet A, are shown in Table 9.3 in bold. Tests for fit of models and significance of the difference between models are given in Table 9.4. From Table 9.4, we see that Model 1—which corresponds to independence for the four variables—is rejected. Models 2 and 3 consider the extent to

Table 9.3: Castanet A End-scrapers (Observed, Expected, and Modified Values)

D	C	B A	Parallel Unretouched	Parallel Retouched	Convergent Unretouched	Convergent Retouched	
Round	Narrow		**33**	**170**	**2**	**84**	Observed
			(61.7)	(162.4)	(9.7)	(25.6)	Expected, based on M_1
			(32.6)	(170.4)	(2.9)	(83.1)	Expected, based on M_{10}
			33	*60*	*0*	*1*	*Modified*
Round	Wide		**15**	**81**	**1**	**2**	Observed
			(30.6)	(80.5)	(4.8)	(12.7)	Expected, based on M_1
			(15.4)	(80.6)	(0.1)	(2.9)	Expected, based on M_{10}
			15	*29*	1	*1*	*Modified*
Medium	Narrow		**96**	**191**	**13**	**31**	Observed
			(80.2)	(210.9)	(12.6)	(33.2)	Expected, based on M_1
			(97.1)	(189.9)	(12.4)	(31.6)	Expected, based on M_{10}
			96	191	*1*	*4*	*Modified*
Medium	Wide		**59**	**112**	**0**	**2**	Observed
			(39.7)	(104.5)	(6.3)	(16.5)	Expected, based on M_1
			(57.9)	(113.1)	(0.6)	(1.4)	Expected, based on M_{10}
			59	112	0	2	*Modified*
Shallow	Narrow		**57**	**98**	**7**	**19**	Observed
			(48.7)	(128.1)	(7.7)	(20.2)	Expected, based on M_1
			(56.9)	(98.1)	(8.4)	(17.6)	Expected, based on M_{10}
			57	98	*1*	2	*Modified*
Shallow	Wide		**45**	**78**	**2**	**0**	Observed
			(24.1)	(63.5)	(3.8)	(10.0)	Expected, based on M_1
			(45.1)	(77.9)	(0.6)	(1.4)	Expected, based on M_{10}
			45	78	2	0	*Modified*

Modified from Sackett 1966.

Table 9.4: Castanet A End-scrapers (Test for Model Fit and Improvement of Model Fit)

i	Model i	L_i	df_i	p value	LLR Difference ($L_i - L_j$)	$df_i - df_j$	p value
1	A,B,C,D	231.1	18	0.000			
2	AD, B, C	165.2	16	0.000	$L_1 - L_2 = 65.9$	2	0.000
3	A, BC, D	138.4	17	0.000	$L_1 - L_3 = 92.7$	1	0.000
4	AD, BC	72.5	15	0.000	$L_2 - L_4 = 87.7$	1	0.000
					$L_3 - L_4 = 60.9$	2	0.000
5	All 2-way interactions	15.9	9	0.068			
6	ABD, C	112.2	11	0.000	$L_2 - L_6 = 53.0$	5	0.000
7	A, BCD	88.7	11	0.000	$L_3 - L_7 = 49.7$	6	0.000
8	ABD, BC	19.5	10	0.035	$L_6 - L_8 = 92.7$	1	0.000
9	AD, BCD	22.8	9	0.007	$L_7 - L_9 = 65.9$	2	0.000
10	ABD, BCD	9.7	6	0.14	$L_8 - L_{10} = 9.8$	4	> 0.05
					$L_9 - L_{10} = 13.1$	3	< 0.005
11	ABC, ABD, BCD	7.0	4	0.138	$L_{11} - L_{10} = 2.7$	2	> 0.20

Modified from Read 1974b.

which interaction between a pair of variables significantly increases the fit of a model over Model 1. Models 2 and 3 have the highest LLR difference values in comparison to Model 1 for all models with a single interaction term. Each of these models provides significantly better fit than Model 1 (see LLR Difference column), but neither model yet fits the data (see L_i column). Model 4, which includes both interaction terms, fits significantly better than either Model 2 or 3 but is still rejected as not fitting the data. Model 5 includes all possible two-way interaction terms and fits the data at the 5% significance level. However, the large number of two-way interaction terms does not seem plausible since each two-way interaction would correspond to a different mode in the production of end-scrapers.

Models 6 and 7 explore the possibility of a single three-way interaction term and each model has significantly better fit than a corresponding model with a single two-way interaction term, but neither of these models fits the data. Model 8 and 9 explore the possibility of a single three-way interaction term coupled with a two-way interaction term. Again, each model provides significantly better fit, but neither model fits the data. Model 10 uses the two three-way interaction terms from Models 6–9, provides a significantly better fit than Models 8 or 9, and fits the data. Finally, Model 11 includes all three three-way interaction terms and fits the data but does not provide better fit than Model 10. Thus, on the basis of parsimony, we accept Model 10—rather than Model 5—as the model best fitting the data.

Step 2: Identify Deviant Cells and their Modified Values Based on Observed versus Expected Cell Values

Corresponding to Model 10 are two three-way contingency tables, *ABD* and *BCD* (see Table 9.5). Next we examine these two tables for the cell frequency counts that deviate most significantly from the expected values for the cell frequency counts. The greatest deviation occurs with the Round-Narrow-Convergent cell in Table *BCD*. Using the iterative procedure for reaching convergence, the modified value for this cell (rounded off to a whole number) should be 17. The table with this modified cell value still does not fit the data when testing for independence of the three variables defining the table (LLR = 55.8, df = 6, p = 0.000).

The next cell in this table that needs modification is the Medium-Narrow-Convergent cell. When this cell is modified, the Round-Narrow-Convergent cell also needs to be modified again since change in the Medium-Narrow-Convergent cell affects the computation of the expected value for the Round-Narrow-Convergent cell.

Table 9.5: Two Castanet A Three-Way Contingency Tables Based on BCD and ABD

A: Marginal Table BCD

	Parallel	Convergent
Round Narrow	203	86 (3)* 97% decrease
Round Wide	96	3
Medium Narrow	287	44 (5)* 89% decrease
Medium Wide	171	2
Shallow Narrow	155	26 (3)* 88% decrease
Shallow Wide	123	2

B: Marginal Table ABD

	Unretouched	Retouched
Round Parallel	48	251
Round Convergent	3	86
Medium Parallel	155	303
Medium Convergent	13	33
Shallow Parallel	102	176
Shallow Convergent	9	19

C: Marginal Table AD (frequency counts are recomputed after modifying cell values in Marginal Table BCD).

	Unretouched	Retouched
Round	49	256 (91)* 64% decrease
Medium	156	309
Shallow	105	178

* (n) is a modified value; see text for details. Modified from Read 1974b: Table 6.

Even after cell values converge for both of these two cells simultaneously, the three variables are still not independent for the modified table and we find that the Shallow-Narrow-Convergent cell also needs to be modified. When convergent values are obtained for these three cells jointly, the three variables are independent (LLR = 9.95, df = 4, p = 0.04) at a 1% significance level for the modified table. The pattern for change in the cell values in Marginal Table *BCD* indicates that the Narrow-Convergent end-scrapers are more frequent than expected in a manner essentially independent of the shape of the end of the end-scraper (see values for percent change in Table 9.5).

Step 3: Modify Cell Values in Full Contingency Table and Retest for Variable Independence

We now modify the full four-way table based on the changes for Table *BCD*. We change the Unretouched and Retouched counts in the four-way table for the three cells that have been modified in Table *BCD*, using the percentage change for each of those three cells shown in Table 9.6.

Table 9.6: Castanet A Modified Cells

Cell	Observed Value	Modified Value	Percent Decrease
round-narrow-convergent	86	3	97%
medium-narrow-convergent	44	5	89%
shallow-narrow-convergent	26	3	88%
round-retouched	256	91	64%

LLR (Model 1, Table 9.4) = 231.1, df = 18, $p < 0.001$.
LLR (Modified) = 16.23; df = 14, $p > 0.70$.

After making these changes, the Model (*ABD*, *C*) (without the second three-way interaction term) now fits the modified data (LLR = 13.74, df = 8, $p = 0.10$) after the changes are made in the cell values. Even more, a simpler model with a single two-way interaction term, (*AD*, *B*, *C*), now fits the data (LLR = 16.46, df = 13, $p > 0.10$). Hence, we do not need to keep the three-way interaction term and can just consider the *AD* table. For the *AD* table, the cell, round-retouched (frequency count = 256) is the most deviant in terms of having a frequency count greater than expected. A modified value of round-retouched = 91 is computed for this cell (see Table 9.5 C).

Next, we modify the four cell values in the full four-way table corresponding to the round-retouched attribute combination, using the percent decrease of 64% for the round-retouched cell (see fourth row of values in Table 9.6). Finally, we compute the LLR value for the full four-way table based on the modified cell values. Now the four variables are independent (LLR = 16.23, df = 14, $p > 0.70$) for the modified table (see rows labeled modified with frequencies in italics in Table 9.3).

Determine the Usage Types

Taken at face value (i.e., ignoring any possible problems with the way the nominalized variables were defined), these data determine two usage types: (1) narrow-convergent (composed of six cells with $n = 156$) and (2) round-retouched-parallel (composed of two cells with $n = 251$) end-scrapers (but see below). Of the remaining sixteen cells, all cells with convergent sides have frequencies ≤ 2 and are thus sporadic cases and not types.[7] Hence, we can include these six convergent cells with usage type 1 and respecify the first usage type as "end-scrapers with convergent sides."

This leaves us with the twelve cells where the sides are parallel. These cells are formed by three independent variables—shape of end, width of end-scraper, and retouch (LLR = 7.2, df = 7, $p = 0.412$). However, two of the nominal variables (roundedness and width of end-scraper) are based on quantitative variables that measure, for the unretouched end-scrapers, the morphology of the end-scraper blanks obtained from a core

rather than being a form imposed on the blank by the artisan. Since the nominal variable, retouch, is independent of the shape and width of the end-scrapers, it follows that just the shape and width nominalization is imposed for all these end-scrapers and so this group of cells reduces to two additional usage types: (3) retouched ($n = 568$) and (4) unretouched ($n = 305$).

Model for Abundance of Round-Retouched End-scrapers

The $n = 337$ round-retouched end-scrapers are ambiguous in this classification since of these end-scrapers, $n = 256$ are included in usage type 2 (based on modified data); and of these, $n = 91$ of them are "extra" members of usage type 2 (see Table 9.5 C). The remaining $n = 81$ round-retouched end-scrapers are part of usage type 1. It appears that round-retouched end-scrapers are simply more abundant than expected rather than forming a distinct usage type. This observation is supported by the data in Table 9.7, where we compare the shape of the end of the end-scraper with the presence of retouching. The most deviant cell is the round-retouched cell and a modified value of 97 is computed for this cell. Next we ask about the source for the extra round-retouched end-scrapers. The answer is found by comparing the Castanet A end-scrapers with the end-scrapers found at a nearby site, Ferrassie H.

Table 9.7: Castanet A End-scrapers (Observed and Expected Values)

	Unretouched	Retouched	
Round	51	337 (97)*	Observed
	(51)	(97)	(Expected)
Medium	168	336	Observed
	(173)	(331)	(Expected)
Shallow	111	195	Observed
	(106)	(200)	(Expected)

* Modified values based on $e_{12}{}^* = [n_{1.}n_{.2} - n_{12}(n_{1.} + n_{.2} - n_{12})]/(n_{..} + n_{12} - n_{1.}n_{.2}) = [388 \times 868 - 337 (388 + 868 - 337)](1198 + 337 - 388 - 868) \approx 97$.
LLR = 0.70, df = 1, $p < 0.40$, based on modified data.

Table 9.8 is similar to Table 9.7, except that the data are from Ferrassie H. Like the Castanet A end-scrapers, a single combination, round-retouched end-scrapers, has more than the expected number of end-scrapers. If we compare the modified Tables 9.7 and 9.8, we find that the proportion of round to medium unretouched end-scrapers is almost identical in the two tables (Round/Medium = 0.30 for both sites), but there are more shallow end-scrapers in Ferrassie H and there are more retouched end-scrapers at Castanet A. The equivalence between the proportion

Table 9.8: Ferrassie H End-scrapers (Observed and Expected Values)

	Unretouched	Retouched	
Round	154	122 (69)*	Observed
	(154)	(69)	(Expected)
Medium	522	247	Observed
	(532)	(237)	(Expected)
Shallow	534	223	Observed
	(524)	(233)	(Expected)

* Modified valued based on $e_{12}^* = [n_{1.}n_{.2} - n_{12}(n_{1.} + n_{.2} - n_{12})]/(n + n_{12} - n_{1.} - n_{.2}) = [276 \times 592 - 122(276+592-122)]/(1802+122-276-592) \approx 69$.
LLR = 1.22, df = 1, $p < 0.30$, based on modified data.

of round and medium unretouched end-scrapers, the larger proportion of shallow end-scrapers at Ferrassie H, and the abundance of round-retouched end-scrapers at Castanet A suggest the possibility that the "extra" round-retouched end-scrapers may have been made from shallow end-scrapers.

To test this hypothesis, we simply add the "extra" round-retouched end-scrapers at each site to the shallow-retouched end-scrapers and compare the proportions of round-medium-shallow end-scrapers, regardless of retouch. This gives us Table 9.9. The remarkable degree of agreement between the two sites strongly suggests that the "extra" round-retouched end-scrapers started out as shallow end-scrapers and were either modified into round end-scrapers through retouching the side of the end-scrapers, or went through a reduction process during usage from shallow to medium to round via retouching the side of the end-scraper.

Table 9.9: Castanet A and Ferrassie H End-scrapers (Observed and Expected Values)

	Castanet A	Ferrassie H	
Round	148	223	Observed
	(148)	(223)	(Expected)
Medium	504	769	Observed
	(508)	(765)	(Expected)
Shallow +"extra"round-retouched*	546 = 306 + 240	810 = 757 + 53	Observed
	(541)	(814)	(Expected)

* Based on Tables 9.7 and 9.8.
LLR = 0.10, df = 2, $p = 0.95$.

However, the abundance of end-scrapers with both parallel sides and retouching, the difference in the proportion of "extra" shallow end-scrapers, and the data in Tables 9.7–9.9 are not consistent with a reduction process that went continuously from shallow to medium to round end-scrapers. This suggests that a portion of the shallow end-scrapers were

made directly into round end-scrapers through retouching the side of the end-scraper.[8] Hence, usage type 2 should just be round-parallel end-scrapers. This implies that the retouch in some instances was a deliberate way to change the shape of an end-scraper from shallow to round-ended. (For other end-scrapers, retouching may have been due to usage as argued by Dibble [1995]). Thus, it appears that there is no conceptual distinction in usage between unretouched and retouched end-scrapers and therefore usage types 3 and 4 can be dropped. This leaves us with the following usage types: (1) convergent end-scrapers, (2) round/parallel end-scrapers, and (3) all other end-scrapers. The same conclusion is reached for the end-scrapers at Ferrassie H.

Comparison Group: Ferrassie H End-scrapers

We can build a series of models for the Ferrassie H end-scrapers parallel to the models for the Castanet A end-scrapers. This series of models is less complex than that for the Castanet A end-scrapers (compare Tables 9.4 and 9.10) and only requires a model with two two-way interaction terms for the four variables. The two-way interaction terms are the same as those found for Castanet A, implying that the end-scrapers at Ferrassie H have essentially the same structure as the end-scrapers at Castanet A.

Table 9.10: Ferrassie H End-scrapers (Test for Model Fit and Improvement of Model Fit)

i	Model i	L_i	df_i	p value	LLR Difference ($L_i - L_j$)	$df_i - df_j$	p value
1	A,B,C,D	123.3	18	0.000	$L_1 - L_2 = 22.6$	2	0.000
2	AD, B, C	100.7	16	0.000	$L_1 - L_3 = 92.3$	1	0.000
3	A, BC, D	31.0	17	0.000	$L_2 - L_4 = 87.3$	1	0.000
4	AD, BC	13.4	15	0.570	$L_3 - L_4 = 17.6$	2	0.000

In both sites, we conclude that there are three possible usage types (assuming all or most of the types making up the paradigm structure for the end-scrapers are culturally salient) consisting of (1) convergent end-scrapers (whether retouched or unretouched), (2) round/parallel end-scrapers, and (3) all other end-scrapers. Because validity of the paradigmatic types determined from the nominalization of the four variables is uncertain (since the nominalization may be imposed and not based on multimodality in frequency distributions), it is equally uncertain whether we have distinguished types or usage types. We would have a usage type, but not a type, if the group of end-scrapers making up the possible usage type can be subdivided into two or more types (based on modes) by using the subdivision procedure discussed in Chapter 8.

If the subdivision procedure leads to just one type whose members are the end-scrapers in question, then we would have determined a type (based on patterning of modes over the end-scrapers) that is also a usage type (based on frequency counts). But we do not know if the attributes distinguished by Sackett are modes; that depends on whether Sackett's nominalization of the end-scrapers was imposed, or whether it is a consequence of bimodality in the frequency distribution for a morphological variable (or clusters in a scattergram plot for pairs of variables). The status of the usage types in comparison to the types (and whether all the types are valid) cannot be resolved with these data.

In both sites, a portion of the shallow blanks (but with different proportions in the two sites) was made into round end-scrapers through retouching the side of the end-scrapers. Of these end-scrapers, some were convergent and thereby were part of usage type 1, and others were round/parallel and thereby part of usage type 2. In other words, the conversion of shallow end-scrapers to round end-scrapers was a single process that had two outcomes: (1) increase in the number of usage type 1 end-scrapers and (2) increase in the number of usage type 2 end-scrapers. This conclusion is corroborated by the fact that the $n = 240$ "extra" round end-scrapers from Table 9.7 are almost precisely matched by the sum of the $n = 83$ "extra" round-parallel end-scrapers due to the interaction among variables B (Side), C (Width), and D (End Shape) (see Table 9.5 A) and the independent computation of $n = 165$ "extra" round-convergent end-scrapers due to the interaction between the variables A (Retouching) and D (End Shape) (see Table 9.5 C).

This analysis illustrates that we can make evident patterning beyond what is expressed in a typology by considering the type frequencies arising from the activities in which the types were utilized. The frequencies, rather than being the basis for defining types, enable us to go beyond what is expressed in the typology by using them to make evident patterning introduced through the usage of the types. The striking similarity—if not identity—between the frequency counts for the Castanet A and Ferrassie H end-scrapers that emerges once the "extra" round end-scrapers are taken into account is unexpected and implies a connection between these two assemblages that heretofore was not observed. The connection is all the more striking when we take into account the fact that a seriation of these and other Middle Paleolithic assemblages in the Vézère Valley in France shows Castanet A to be much older than the nearby site, Ferrassie H (Sackett 1966). Hence, this is a pattern of end-scraper modification that has considerable time depth. Do yet other assemblages share the same pattern of essentially identical, initial end-scraper frequencies then being modified through transforming shallow end-scrapers into round end-scrapers, but at different rates? What does this imply about regional

patterns in site assemblages, both spatially and temporally, in the Middle Paleolithic? Do the three usage types identified in the analysis simply represent resharpening during tool usage, as argued by Dibble (1995)? If so, why would resharpening introduce three distinct groups of end-scrapers? If not, what are the functional differences among these three usage types? Or are the differences due to processes more complex than just tool usage and function?

The end-scraper analysis illustrates how quantitative analysis should extend archaeological reasoning, both by answering initial questions and uncovering unanticipated patterning that generates new directions for research. Sackett's question ("Are rounded front contours and body convergence the accidental by-product of applying marginal retouch to an end-scraper, or did the artisan willfully employ retouch in order to obtain these features?") has been answered here in favor of the second alternative. One of the directions implied by the patterning uncovered through the analysis of the end-scraper frequencies relates to the explanatory basis accounting for the similarities and differences in the end-scraper frequencies. As noted by Sackett, "The manufacture of end-scrapers involved a series of choices ... and it appears that the decisions . . . were influenced by *cultural factors* . . . [and] largely concerned *systematic evolution* within a regional Aurignacian stylistic tradition. . . . Both *style* and *function* might in fact be involved simultaneously" (1966: 389–390, emphasis added). The results obtained here reflect the same considerations. How we incorporate style, function, and evolution of traits in our analysis is the topic of the next chapter.

10

Style, Function, Neutral Traits, Evolution, and Classification

Style as a Residual Category

Style and function are intuitively appealing concepts we can bring to archaeological classification based on our interaction in daily life with our own artifacts. In this interaction, we routinely distinguish between functional and stylistic aspects of artifacts and it is but a short step to extend our experiential knowledge to the domain of artifact classification by introducing a distinction between functional and stylistic types.[1] The usefulness of this distinction is virtually self-evident when we consider the manner in which style and function can refer to different ways in which we integrate material culture and behavior. For example, explanatory arguments regarding the spatial and temporal patterns for the relationship between production and use of artifacts may be of a different kind when we are concerned with functional—as opposed to stylistic—aspects of artifacts. This, and other behavioral consequences relating to the difference between function and style, implies the need for a distinction between functional and stylistic traits that can be implemented analytically.

To do so, we might attempt to begin with our intuitive (though not necessarily precise) notion of the functionality of an artifact as referring to characteristics directly relating to its usefulness and efficacy for performing a task. Style has then been defined, though not without difficulty, as a residual category composed of all nonfunctional characteristics that are not subject to material and technical constraints (Binford 1962, 1965; Voss 1977; Wilmsen and Roberts 1978; Close 1979; Rick 1980). Nonfunctional traits, it has been argued, will have more differentiated spatial and temporal distributions than functional traits, and this has led to using changes in style defined to identify the cultural-historical-spatial context of artifact

types (Sackett 1977; Plog 1983), but only by making overly simplified assumptions about the occurrence of style innovation, the spatial and temporal diffusion of stylistic traits among artisans, and the pattern for change in the relative frequency of stylistically based artifact types in a particular spatial-temporal context.

That nonfunctional traits tend to have spatial-temporal variation on a scale comparable to the spatial-temporal scale needed for both descriptive and analytical arguments regarding the spatial-temporal distribution of artifacts has led to "stylistic" classifications for which delineating space-time systematics became "an end in itself," whereas the more fundamental "problem of why changes in stylistic attributes might occur was never directly addressed" (Shanks and Tilley 1987a: 138). Pottery and lithic classifications have often been reduced to constructing a dating device rather than addressing the relationship between the patterning found in material cultural remains and the dynamics of the social and cultural system or systems in which the production of material culture has been embedded (Taylor 1948). To this general criticism about reducing classification to a dating exercise, and thereby ignoring the broad array of information embedded in nonfunctional traits that relate to the social and cultural systems in which the production and use of material culture was embedded, we may also add a more specific problem: delineating negatively what constitutes a stylistic attribute by reference to a residual category simply sidesteps and does not address directly the complexity of the phenomena grouped together as stylistic.

Analytical Distinction Between Style and Function

The appeal of defining style as a residual category lies in making a logical division of traits into functional and stylistic traits, thereby reducing the analytical problem to one of delineating what constitutes a functional trait. Though logically valid, the division presumes that traits are either functional or stylistic and forces us to analytically assume that even though style is defined as a residual category, it nonetheless is a homogeneous category with respect to processes underlying the patterning that we discern in the spatial and temporal distribution of stylistic traits. If traits defined as style in this manner did form a homogeneous category, we should be able to define what constitutes style other than by the negative definition of being a residual category. But the fuzziness of our intuitive notion of style as a residual category becomes evident when we try to make a definitional distinction between function and

style, since the same artifact trait can be viewed from both the perspective of function if we consider how it can be used, or from the perspective of style when we take into account the social context in which the artifact is embedded and how this affects the form and decoration of artifacts (Shanks and Tilley 1987a; Graves 1994; Sinclair 1995; Gamble 1998).[2]

Even if we try to distinguish between functional and stylistic traits by considering just the relationship between a trait and an activity involving an artifact with that trait, we need not always find a sharp distinction. On the one hand, a trait making up part of the form for the handle of a hammer may be functional in that the handle—through its attachment to the hammer head—enables the kinetic energy provided by the arm and wrist movement to be transferred to the object being struck by the hammer, whereas the color of the handle is stylistic in that the action of the hammer is equally well achieved regardless of the color of the handle. Here the difference between style and function for a trait is clear. On the other hand, a bowl might be used in a ritual activity only when it has a particular decoration because the decoration is conceptually linked to performing the ritual—for example, the use of red painted pottery in religious ceremonies by the Dangwara of Central India (Miller 1985). The same argument that says a morphological trait is functional by virtue of its role in the performance of an activity such as hammering equally says that the decoration on the bowl used in a ritual is functional (Sackett 1977) even though decoration is usually considered to be stylistic. Yet intuitively the functionality of a hammer handle trait when hammering objects and the functionality of the decoration of a pot in the performance of a ritual are different. More precisely, the former has utility in reference to the material/phenomenological domain whereas the latter has utility in reference to the ideational domain. This difference in the source of the utility enables us to more precisely define a difference between stylistic and functional traits.

We can distinguish between utility in these two domains by considering whether it is possible to perform the same activity with the artifact and trait in question in an equally efficacious manner when characteristics of the trait are changed. Changing the form of the handle of the hammer can affect both the manner in which the kinetic energy of the moving arm is transmitted to the hammer and the accuracy with which that kinetic energy is transmitted to an object when it is struck with the hammer; hence, the change can affect the efficacy with which the task in question may be carried out. Thus, there is feedback to the user via change in efficacy when doing a task if there has been change in the form of the handle. That is, changes in the phenomenological domain (namely the form of the handle) may affect the efficacy with which a task can be performed.

Change in the decoration of the bowl may also affect its use in a ritual but for a different reason. The bowl may still be equally efficacious as a

bowl (that is, its utility in the material/phenomenological domain has not changed), but the meaning associated with the bowl + decoration in the context of the ritual may have been altered by the trait change and thereby made the modified bowl unsuitable for use in the ritual. If, however, there were a perceptual change so that the meaning of the original decoration is conceptually shifted to the modified bowl decoration, then the modified bowl could now be appropriate for use in the ritual activity in question.[3] The same is not true of the modified hammer. Regardless of how the modified hammer might be perceived, the loss of efficacy in doing the same task with the modified hammer arises from the way the artifact and action using the artifact are embedded in a phenomenological domain of material consequences.

Function is to Style as Phenomenological is to Ideational

We find a crucial difference in these two examples when we consider the consequences of variation in the artifact for efficacy in performance at the phenomenological versus ideational level. This suggests that we distinguish a functional trait as one in which variation in the values for a trait have consequences at a phenomenological level in accordance with physical properties, mode of energy transfer involved in doing an activity with an artifact, and so on, when using an artifact with the trait in question for some task. In a stylistic trait, variation in the values for the trait has consequences at the ideational level and may thereby alter a conceptual relationship between the artifact on which that trait is embedded and the performance of an activity with that artifact. Style, in this sense, is not merely a passive, residual category consisting of all nonfunctional traits. Instead, it refers to aspects of the material domain that reflect the ideational domain and manifestations of the ideational domain as they might relate to activities and interactions among individuals and groups of individuals (Hodder 1985; Miller 1985; Shanks and Tilley 1987a, 1987b; Timmins and Staeck 1999).

Under this definition, both a functional and stylistic trait may be subject to the user's (or users') evaluation of the efficacy of using the artifact with the embedded trait for the activity in question. What will differ is the source of the information and the framework for making that evaluation. For a functional trait, feedback in the form of evaluation arises from the phenomenological level with regard to the difficulty or ease with which the activity at hand may be performed when doing a task involving an artifact with the trait in question. Efficacy can be measured at the phenomenological level through energy expended, time required to do a fixed task, and so on. For a stylistic trait, the feedback information arises from the ideational domain and relates to the meaning or interpretation made of that trait for the context in which the artifact is being employed.

Trait Selection: Functional versus Stylistic Selection

The information feedback may lead to selection, which can occur in several different ways. For a functional trait, users select artifacts for a task in accordance with perceived effectiveness in doing the task in question. Does one artifact/tool enable the user to do the task at hand with less time and/or energy than a different artifact/tool? Or users may be motivated to modify the trait in question when the artifact does not do the task effectively, such as resharpening a dull tool. Yet another possibility is that the user (or user interacting with an artisan) may be motivated to innovate and change characteristics of the trait as a way to do the task more effectively, or even to make a different kind of artifact for doing the task at hand.

Functional traits lend themselves to these forms of selection through evaluation of the efficacy of artifact usage by the individual user. Each time an artifact is used for a material task, the user receives immediate feedback with respect to the effectiveness of the artifact with the trait in question for doing the task at hand. The user—depending upon circumstances—may respond to negative feedback by (1) selecting a different artifact for the task when the task is next performed, (2) modifying the artifact if possible, or (3) informing the artisan who produced the artifact that the artifact is unsatisfactory for the task at hand.

Though the feedback and selection occurs at an individual level, the kind of feedback that is obtained from the phenomenological domain when a task is performed with the artifact having the trait in question will be similar regardless of the particular individuals involved. That a dull knife takes more time and effort than a sharp knife on the part of a user for the same cutting task is true for all users. Hence, there will be a tendency for changes in trait characteristics to converge to a similar value regardless of the particular user since each user receives the same feedback and may therefore respond selectively in a similar manner.

A stylistic trait is constrained in a different manner. Here constraint relates to the efficacy of using an artifact with the stylistic trait in conjunction with events evaluated at an ideational level. A particular stylistic design may, as part of a broader conceptual system, be efficacious in terms of the meaning attributed to the stylistic design (implicitly or explicitly) by the users of the artifact in a particular context, or symbolic content (if any) may be constrained by the way it expresses social relations (Braithwaite 1982; Hodder 1982; David 1983; Tilley 1984; Welbourn 1984; Shanks and Tilley 1987a, 1987b; Mead 1990; Lemonnier 1993). Other constraints are possible; one stylistic trait may simply be more aesthetically pleasing for the users (which has its own conceptual system that relates to what constitutes "aesthetically pleasing") for example, when the design is based

on symmetries (Hardin 1984; Washburn and Crowe 1988) or on a more complex geometry such as fractals (Eglash 1999).

In general, stylistic traits will converge to a similar value only when there is congruence among artisans and users with regard to evaluation at an ideational level; that is, congruence in a value for the trait—if there is congruence—may be culturally dependent and arise through a shared ideational domain. In some cases, congruence can relate to social boundaries, though in other cases it may crosscut ethnic differences (Hegmon 1992 and references therein) since the ideational domain invoked for evaluation of stylistic traits need not be coterminous with social or ethnic boundaries.

Typology for Nonfunctional Traits

Selection for stylistic traits is more complex by virtue of being linked to an ideational domain and so there is no single measure—such as efficacy in the performance of a task at a phenomenological level—that identifies the trait value to which selection will converge, if at all. Instead, we have two possible general outcomes for selection at the ideational level.[4] First, because possible values for the trait are evaluated in a similar manner by all (or most) users, there is convergence to a modal value (in the sense of Rouse) for the trait—regardless of artisan—in response to those evaluations, but the modal value to which there is convergence is not predictable from outside the ideational system (Sackett 1985). Second, there may be convergence to a restricted range of values but with no single modal value characterizing each artisan. (We will see an example of this possibility below.)

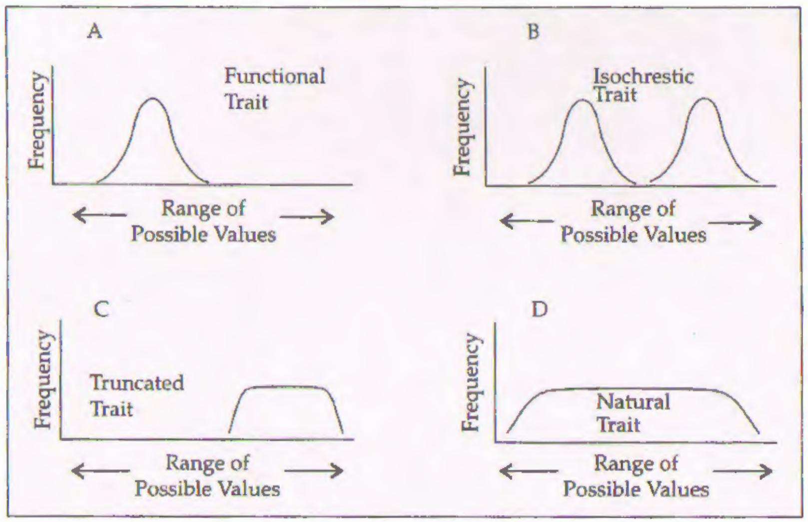
Another possibility, neither included under stylistic nor functional traits as they have generally been defined, is lack of patterning in the way a trait might be evaluated—or even not evaluated. In this case, there will neither be convergence among the artisans to a range of values nor to a modal value. Let us refer to a nonfunctional trait for which there is no convergence as a *neutral* trait.

For non-neutral and nonfunctional traits, let us borrow from Sackett (1982) and refer to a nonfunctional trait for which there is convergence among a community of users and artisans to a modal value as an *isochrestic* trait.[5] Let us refer to a nonfunctional trait for which there is convergence to a restricted range of values—but without a modal value—as a *truncated* trait. Whether there will be convergence, either to a modal value or to a truncated range, will depend on the particular community of users and artisans. One kind of trait can be combined with another, as in a truncated trait for which there is also convergence to a modal value.

We can translate the four different kinds of traits—functional, isochrestic, truncated, and neutral—into different expected patterns for a frequency distribution in comparison to the possible range of values for a trait (Read 1982). By a *possible range of values* will be meant the range of values that are consistent with any physical or material limitations arising from the physical nature of objects (including technological/production limitations) when making an artifact with the trait in question. The angle of the tip of a stone projectile point, for example, can be made physically with an angle close to 0 degrees but will be extremely fragile and thus not a viable projectile point. The wall of a pottery vessel can range from very thin to very thick from the viewpoint of modeling the clay from which the vessel is made, but the technique for firing the clay may restrict the thickness of the clay that can be fired without cracking. Yet even with a technological constraint, a relatively wide range of wall thicknesses is still physically possible; hence, wall thickness of pottery will still have a relatively wide range of possible values.

The frequency distribution patterns that distinguish the four kinds of traits are shown in Figure 10.1 (A–D). Functional traits will have a unimodal frequency distribution with the magnitude of the variance in trait values small in comparison to the range of possible values. In addition, the mean of the frequency distribution (and other indicators of functional pattern) will tend to be the same regardless of cultural context (Meltzer 1981; Read 1982). Isochrestic traits will share with functional traits a unimodal distribution and small variance in comparison with the

Figure 10.1: Expected frequency distribution pattern for functional, isochrestic, truncated, and neutral traits



range of possible values, but will differ from functional traits by a mean value that may differ from one cultural context to another.[6] Truncated traits will share with isochrestic traits a limited range of values but will tend to have a uniform frequency distribution over that range of values. Finally, neutral traits will have a frequency distribution approaching a uniform distribution over the entire range of possible values.

Examples of Kinds of Traits

Functional Traits

A good example of a functional trait is the tip angle for a projectile point. From an engineering design viewpoint, we would expect the tip angle to be constrained by a variety of material and mechanical factors that relate to the efficacy of an arrow point by taking into account energy transfer to the arrow shaft from a bow, the aerodynamics of an arrow in flight, the impact of the arrow point when hitting an animal, and whether killing is being done by deep penetration into a vital organ or through massive shock to the animal.

These considerations lead us to predict that the frequency distribution for the angle of the tip of the projectile point should match that of a functional trait. In fact, as discussed in Chapter 8, the tip angle frequency distribution for each of the projectile point types from 4VEN39 has the same mean angle regardless of projectile point type, and for each type of point the angle frequency distribution is a unimodal, approximately normal distribution. Similarly, the angle for the tip of Scottsbluff points analyzed by Read (1982) also follows the pattern for a functional trait. The frequency distribution of the tip angle of the Scottsbluff points has the same mean for the ten sites that were analyzed and low coefficient of variation (standard deviation/mean) for each of the sites (Read 1982), even though some of the sites with Scottsbluff points are separated in space by thousands of kilometers and dates ranging from 10,000 to 8,000 BP.

Isochrestic Traits

An unambiguous example of an isochrestic trait is provided by the frequency distribution for the width of the 4VEN39 concave projectile points since it is composed of two distinct unimodal distributions. The small, but systematic, difference in the width of the projectile points does not relate to different hunting tasks and so the difference is isochrestic. Since both types are found in the same site, the data suggest that two cultural groups (such as different lineages) were in the 4VEN39 village.[7] As noted above, having more than one lineage in a village suggests matrilineal—rather than patrilineal—lineages.

The points made by san hunter and gatherer groups in Africa (Wiessner 1983) (see Figure 10.2) provide another illustration of an isochrestic trait. The san points (top of Figure 10.2) have a characteristic triangular shape with an almost perfect normal distribution (see Figure 10.3, where individual measurements for the arrows made by each arrow maker have

Figure 10.2: Three sets of projectile points (made from wire). Modified from Wiessner 1983: Figures 3–5

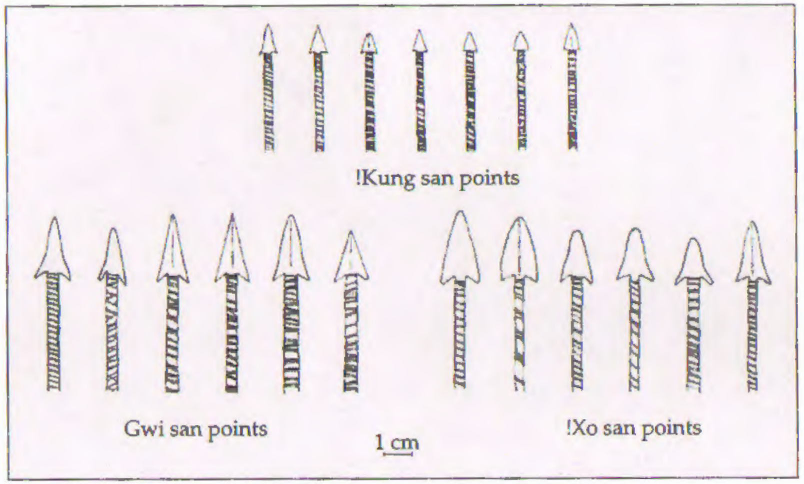
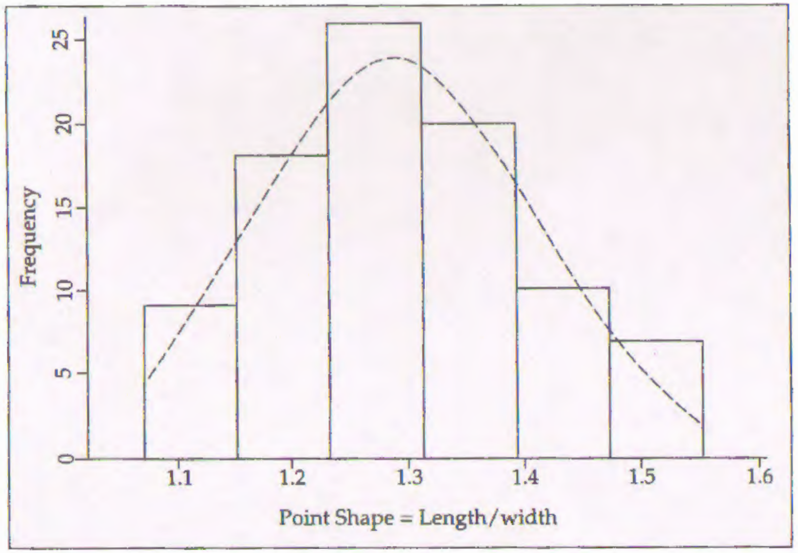


Figure 10.3: Histogram for the shape of the !Kung san points. Based on Wiessner 1983: Table 1



been grouped by the mean value for the arrows made by that arrow maker), as would be expected if there is a single, shared notion regarding the shape of a point that serves as a target shape for each arrow maker.

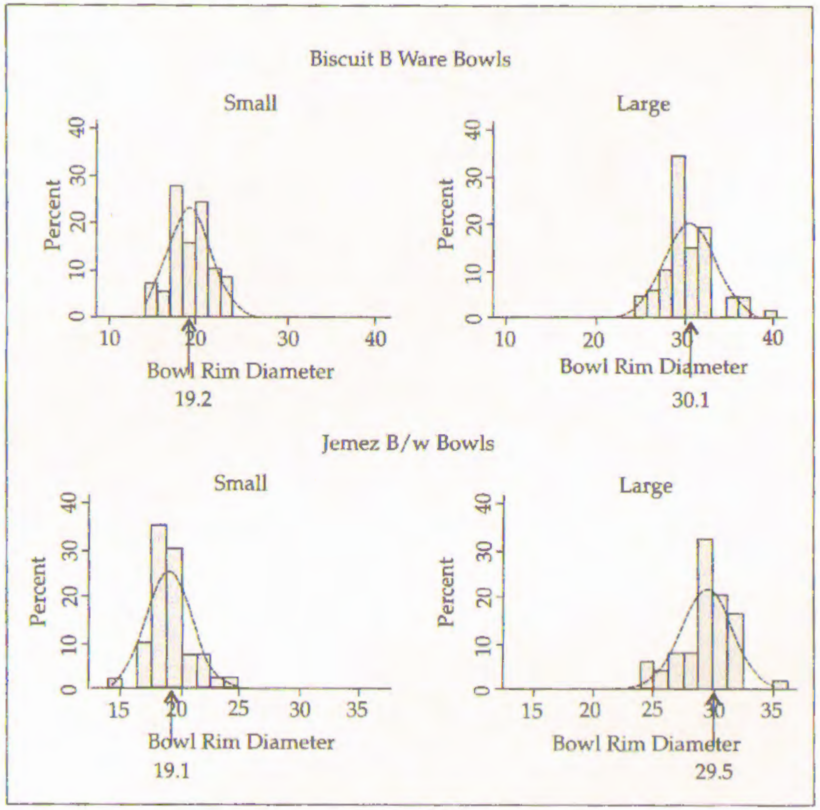
The !Kung arrow points, as a group, differ from the points made by individuals in two other linguistic groups, the !Xo and the G/wi (see Figure 10.3). The points from the latter groups are twice as large as the !Kung points with no overlap in the respective frequency distributions. The !Xo and the G/wi points have a similar size but statistically different shapes (Wiessner 1983). The shape of the points is isochrestic since (1) one of the linguistic groups has converged on a different shape than is the case for the other two groups; (2) the San points have a clear, unimodal shape frequency distribution; and (3) the points are used in the same manner for hunting by each of the linguistic groups. Thus, the different shape values are consistent with the same functional use of the points for hunting.

A less pronounced isochrestic distribution occurs with the rim diameter of pottery bowls made by the prehistoric Tewa and Towa of New Mexico (Morley 2002). The frequency distributions for the bowl diameters are strongly bimodal and approximately normally distributed for each group (see Figure 10.4), so the bowl diameters can be nominalized as Small and Large with 24.5 centimeters the dividing line between Small and Large (Morley 2002). The mean values and variances are virtually identical for each of the two size categories for these two groups (see Figure 10.4). The distributions are approximately normal and the pattern, at first glance, appears to fit that of a functional trait except that there is no obvious reason why bowl diameters should be constrained for functional reasons.

When the bowls are compared on a site-by-site basis, site-specific differences in the mean bowl size for both small and large bowls become apparent. As shown in Table 10.1, the more extreme differences in mean size of small bowls—such as Amoxiumqua versus Otowi small bowls—are statistically different at the 1% level.[8] The differences in diameter among the large bowls are more pronounced and several of the comparisons are statistically significant at the 1% level. In addition, the difference in mean of 3.7 centimeters for the Unshagi versus the Sapawe large bowls is not insubstantial and would be visually evident. Nonetheless, though the means for diameters tend to be site specific, the range of variation in bowl diameter is truncated; thus, bowl diameter is both isochrestic and truncated.

The truncated distribution for mean bowl sizes suggests that the division into small and large bowls may have originated prior to the historical separation of the Towa and the Tewa ancestor populations into two distinct groups. If so, this would imply that the mean values for small

Figure 10.4: Histogram for Tewa (Biscuit B Ware) and Towa (Jemez B/w) bowls. Dashed lines are normal distribution curves for each histogram based on its mean and standard deviation. Vertical arrow points to the mean bowl diameter for each group. Data extrapolated from Morley 2002: Figure 8.1



and large bowls have only had minor changes in size since separation of an ancestral population into the descendant Towa and Tewa groups, even though the constraint on bowl size seems to arise from the ideational domain and not from feedback in the phenomenological domain.

Truncated Traits

Though the shape of the !Kung points form a normal distribution, the size of the !Kung points are distributed more or less evenly throughout the range of sizes for the !Kung points and do not form a unimodal—let alone a normal—distribution (see Figure 10.5). The size range for the San points is truncated: the G/wi and !Xo both make points that

Table 10.1: Comparison of Mean Bowl Sizes by Site and Group (Tewa, Towa)

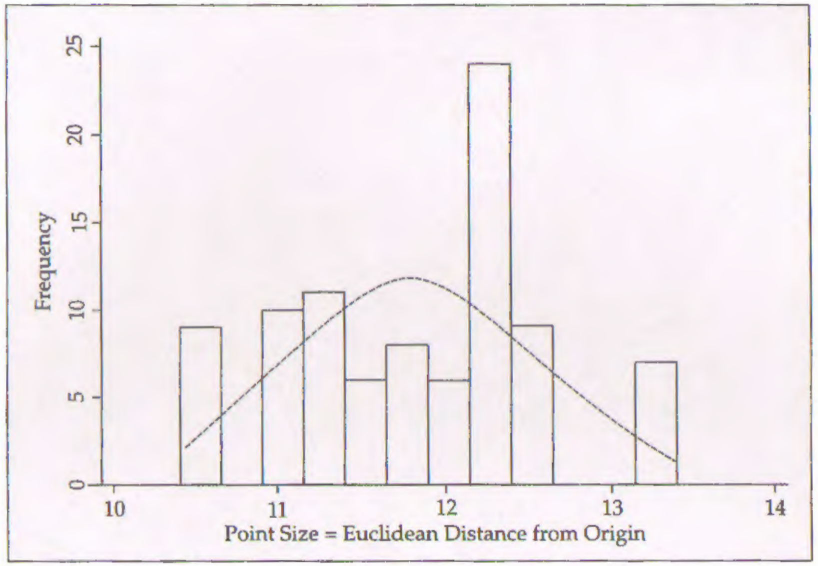
		Small Bowls			Large Bowls		
Ware	Site (Group)	Sample size	Mean	St. Dev.	Sample Size	Mean	St. Dev.
Jemez B/w	Unshagi	7	18.6[2]	1.62	11	29.1[4,5]	1.87
	Amoxiumqua	22	18.7[1]	1.78	16	30.7[6]	1.74
	Guisewa	6	19.8	1.94	11	30.0[7]	1.48
	(Towa)	39	19.1[3]	1.92	48	29.5[8]	2.19
Biscuit B	Otowi	26	20.7[1,2]	2.49	27	31.5[5]	2.32
	Sapawe	5	20.6	3.21	11	32.8[4,6,7]	3.43
	(Tewa)	57	19.2[3]	2.51	67	30.5[8]	2.86

Multiple t-tests for difference in means (H_0: $\mu_1 = \mu_2$)
Each comparison is between two groups with the same superscript

[1] t-test: $t = 3.22$, $df = 46$, $p = 0.002$
[2] t-test: $t = 2.16$, $df = 31$, $p = 0.04$
[3] t-test: $t = 0.26$, $df = 94$, $p = 0.8$
[4] t-test: $t = 3.17$, $df = 20$, $p = 0.005$
[5] t-test: $t = 3.07$, $df = 36$, $p = 0.004$
[6] t-test: $t = 2.13$, $df = 25$, $p = 0.04$
[7] t-test: $t = 2.50$, $df = 20$, $p = 0.02$
[8] t-test: $t = 2.00$, $df = 113$, $p = 0.048$

Site data extrapolated from Morley 2002: Figures 8.5–8.9.

Figure 10.5: Histogram of the point size computed as the Euclidean distance from the origin of a graph of length versus width. Dashed line is a normal distribution curve based on the mean and standard deviation of the data set. The frequency distribution is not normal and is approximately uniform, except for one isolated peak in the histogram. Data from Wiessner 1983: Table 1



are much larger and used in the same manner as the !Kung points (see Figure 10.2). Consequently, the size *range* for the san points is truncated and size *values* are neutral within that range. Other attributes making up the triangular shape are also truncated and vary considerably among individuals and even within the points made by the same individual. Together these attributes enable us to identify the person who made a particular arrow (Wiessner 1983).

Neutral Traits

The frequency distribution for the length dimension of the resharpened points from 4VEN39 is the same for both groups of points and has a wide range of values without pronounced unimodality; as such, it is an example of a neutral trait. This is consistent with the interpretation of the bulk of the concave base points as resharpened, broken projectile points wherein the length of the points tends to be happenstance. The Scottsbluff points also provide an example of a neutral trait, as well as being a good example for showing how the traits can be distinguished by type of trait as one goes around the outline of an artifact via a nonredundant set of measures that satisfy the archival property. Beginning with the tip, the

morphological traits can be separated into functional traits (angle of the projectile point), isochrestic traits (chord length, height of curve above the chord, length of the two base shoulders), and neutral traits (angle forming the base shoulder) when the points are grouped by the site where the points were found and frequency distributions are constructed and compared on a site-by-site basis. (Separation of the data by site reduces the likelihood that a dataset is heterogeneous.)

As discussed by Read (1982), the distinction between functional and isochrestic traits (on the one hand) and neutral traits (on the other), based on the shape of frequency distributions, matches Rouse's distinction between modes and attributes. Both functional and isochrestic traits represent aspects of the artifact for which the trait value introduced by the artisan on the artifact is constrained—either by efficacy when using the artifact in a functional sense or by the manner in which the artifact relates to a shared, ideational domain—and have emic relevance. Neutral traits have values specific to an artisan and are not constrained except possibly by a limitation on the range of values; hence, they do not have emic salience in the sense of a target value shared across different artisans.[9] Truncated traits have not previously been identified as a form of stylistic trait.

Selection and Trait Values

Selection: Functional Traits

The unimodality that characterizes functional and isochrestic traits arises through selection affecting trait values in the production and usage of artifacts. In the absence of any form of selection, the frequency distribution for a trait would tend to have a uniform distribution over the range of possible values. For functional traits, the selection relates to efficacy in doing the task at hand when the artifact is being used as a tool employed in carrying out that task. The mean value of a functional trait will likely be near an optimal value and that, in principle, can be determined by objective criteria based on the materials involved (Bleed 1986; Schiffer 1990a); the physical demands of the task such as cutting, smashing, turning, piercing, and heating (Christenson 1986; Odell and Cowan 1986; Schiffer et al. 1994; Allen 1996); the manner in which kinetic energy is transferred to the artifact-as-tool and from the artifact-as-tool to the object upon which it is acting (Christenson 1986; Bleed and Bleed 1987; Schiffer 1990c); and so on, or with regard to the characteristics of the material from which the object is formed (Braun 1983; Klemptner and Johnson 1986; Titmus and Woods 1986; Schiffer and Skibo 1987; Schiffer 1988; Feathers 1989; O'Brien et al. 1994).

The variance around the mean value will be affected by the intensity of the selection (in the sense of the evaluation made by the user of the efficacy of using an artifact-as-tool in its current form for the task at hand), the cost of ensuring that a trait value is close to an optimal value when making an artifact (Torrence 1989), the time period over which costs will be amortized (Read 2006), and so on. With functional traits, we expect to find little variation in the mean value of the trait between cultural contexts since optimal values in the phenomenological domain are culture independent. There may be variation in the variance of trait values when we compare one context to another. The variance relates to the degree to which a trait value needs to approximate an optimal value for the artifact to perform acceptably and the latter need not be the same in different contexts.

Since the constraints relate to the phenomenological domain, they are accessible to us as well. Trait properties that would make an artifact efficacious for the task at hand in the past still have the same interpretation today. The properties that make an artifact efficacious with respect to the phenomenological domain can be determined through analyzing the relationship between material characteristics and performance of a task, as has been done for the aerodynamic properties of projectile points (Christenson 1986; Cotterell and Deuel 1990). Hence, we can determine the efficacy of one trait value in comparison to another (or one artifact form in comparison to another), and thereby make explicit the feedback that may have led to convergence of trait values to a distribution with the modal value uncovered through analyzing the frequency distribution for a trait. This argument, however, does not apply in the same manner to isochrestic and truncated traits.

Selection: Isochrestic and Truncated Traits

Isochrestic and truncated traits are also subject to selection, but selection arising out of considerations at the ideational rather than the phenomenological domain. Whereas a user in isolation can be an agent for selection with respect to functional traits, selection that stems from the ideational domain relates to social interaction. Selection is in the form of group—and not just individual—evaluation of the efficacy of trait values for the task at hand, since evaluation is at the ideational level of shared values, concepts, and the like (which we include under the rubric of culture). Scottsbluff points made by one group, for example, could have had a different side curvature and still performed equally well for the task of killing an animal, but the community within which the artisan was located presumably rejected a different curvature as inappropriate.[10]

The mean value for an isochrestic trait, as has been noted by a number of researchers, is not predictable from an etic perspective and is characteristic of a particular community and a particular time within that community; hence, it is space and time dependent. Similar comments apply to the boundary values for truncated traits.

Selection: Neutral Traits

It is only with neutral traits that selection will play a minimal role. For a neutral trait, any value within the range of admissible trait values is satisfactory and the wider that range, the less skill required to produce a satisfactory artifact with respect to that trait. If all values in a range of values are equally likely, then we will tend to have a uniform distribution over that range of values—as can be seen in the size of san points, with one exception where the frequency count is much higher than for other values (see Figure 10.5). The exception suggests the possibility that rather than acting independently, one artisan in a community may have decided to imitate another artisan for whatever reason, and through imitation there may be divergence from a uniform distribution toward a uniform distribution with a single peak (as occurs in Figure 10.5).[11] If imitation should be ubiquitous and directed toward a single individual, a target value is thereby introduced and we will now have an isochrestic trait arising—through social interaction—from selection in the form of a propensity to imitate.

Change and Transmission of Trait Values

Whereas the conditions for a functional trait to converge to an optimal value are similar regardless of the cultural context, the same is not true for an isochrestic trait. A trait could be isochrestic in one context, truncated in another context, and neutral in yet another context.[12] Further, the mean value for an isochrestic trait may vary through time in accordance with the basis for the evaluation that leads to convergence on a single value. Imitation of a single artisan as the basis for an isochrestic trait is likely to be prone to change in mean value over relatively short time intervals since the target value can change for a variety of reasons (such as the target individual altering the trait value for idiosyncratic reasons), or there may be a shift to a different target individual. If the changes in mean value are on a scale comparable to variability in individual trait values and occur over a time scale shorter than can be controlled through excavation, the data set brought forward for analysis may appear to be a truncated

distribution even though it is composed of several isochrestic trait values. In addition, there is no reason to assume that imitation is also driving the trait in question to an isochrestic value in a different community of artisans and users.

Isochrestic traits arising from evaluation based on shared values are likely to be more stable than isochrestic values arising from imitation since the former will not, in general, be responsive to change in trait values that are specific to an individual artisan. If the data set brought forward for analysis is accumulating from a number of artisans and covers a time span exceeding the time period of productivity for an individual artisan, then should there be an isochrestic trait for these data; it is likely to be a consequence of shared values or norms rather than imitation. The data on the Tewa and Towa bowls are an example of isochrestic traits that have had little or no change for several hundred years, and thus bowl diameters may represent shared norms regarding appropriate bowl diameters.

Evolutionary Archaeology

As argued by the proponents of evolutionary archaeology, transmission of isochrestic traits through imitation or shared values highlights the complexity of modeling changes in trait values and the frequency of traits through an evolutionary framework based on reproductive fitness. That the three basic components of an evolutionary model—a process for the introduction of new traits and trait values, a means for transmission of trait values from one individual to another through time, and change in frequency of trait values through selection—are relevant to artifact traits and trait values is virtually self-evident. Hence, evolution in the form of change in the frequency of artifact traits is not at issue; less obvious has been what constitutes an appropriate model for evolutionary change in trait frequencies when considering artifacts.

The approach of evolutionary archaeologists has been to translate directly the Darwinian model of evolution based on random mutations and change in frequencies driven directionally through natural selection or nondirectionally through drift of neutral traits to the context of artifacts and artifact traits (Dunnell 1980; Neiman 1995; Hurt and Rakita 2001). Dunnell (1978) has argued that neutral traits should be equated with stylistic traits and the traits affected by selection should be equated with functional traits: "*Style* denotes those *forms that do not have detectable selective values. Function* is manifest as those *forms that directly affect the Darwinian fitness of the population in which they occur*" (p. 199), where form may be at any scale, ranging from attributes to whole artifacts. Dunnell presumes both that his definition of style is "quite close to its usage in

archaeology" and that stylistic traits are "independent of external conditions" (1978: 199), whereas "functional traits interact with their environment" (Dunnell 2001).

These two assumptions have paved the way for an evolutionary archaeology research program that has assumed—but not demonstrated—an identity between selection in the context of artifacts and artifact traits and natural selection in biological evolution, defined in terms of reproductive fitness because of its consequences for allelic frequencies (Rosenberg 1998). Like some early typologists who simply assumed archaeological classification should be copied from biological classification schemes, evolutionary archaeologists assume that the Darwinian model for biological evolution only needs translation of its terms to be applicable to artifacts and artifact traits and this would suffice to account for the spatial and temporal distribution of traits.[13] The translation, as it has been worked out by evolutionary archaeologists, equates functional traits with fitness-based selection and stylistic traits with neutral traits; hence, stylistic traits by definition are not subject to selection (O'Brien and Holland 1992; Lyman and O'Brien 1998).

Evolutionary Archaeology: Function and Style

Although what constitutes evolutionary archaeology has developed beyond Dunnell's initial programmatic statements (Lyman and O'Brien 1998), linking style with neutral traits has remained constant, though Dunnell's assumption that style as it is understood by most archaeologists is captured by the notion of neutral traits has been dropped: "[T]he EA [evolutionary archaeology] model *defines* style as selectively neutral variation, then classifies variation as stylistic if it fits this definition" (Hurt et al. 2001: 742). The authors go on to claim that if a trait has patterning inconsistent with a neutral model, then selection has occurred and therefore—in the evolutionary archaeology framework—the trait must be functional and so the patterning should be subsumable under a Darwinian model of natural selection (= fitness based selection) acting on a functional trait.[14] This assumption, however, is problematic. The opposite of a neutral trait is not a functional trait undergoing natural selection, but can be any one of several different kinds of traits (as discussed above) and the mode of selection need not be fitness based.[15]

In Figure 10.1, we identified four patterns for the frequency distribution of trait values at a point in time (more precisely, for a time interval short in comparison to the time scale for measurable evolutionary change to have taken place), only one of which corresponds to a biologically neutral trait. Of these four patterns, only the pattern for a neutral trait entails

the hypothesis that the trait in question has variation unconstrained by selection, and thus is comparable to the notion of a neutral trait espoused in evolutionary archaeology. The functional trait, as shown in Figure 10.1, presumes that selection has both constrained the range of possible values—and the location of the mean for the trait—on the basis of feedback arising from the phenomenological/material domain, when the artifact with the trait in question is employed as a tool for performing a task. While superficially similar to the evolutionary archaeology notion of a functional trait, it differs significantly with respect to the source of the selection. The evolutionary archaeology position assumes that selection is natural selection; hence, the currency for measuring selection lies in individual fitness values (Cochrane 2001: 18).[16]

The reason for insisting on individual fitness as the currency for measuring the basis for evolutionary change in functional traits is unclear. In the biological context, individual fitness arises as the currency for measuring the potential for evolution by virtue of evolution being defined in terms of change in allele frequencies, and individual fitness is a primary means by which allelic frequencies will change through time. The frequency distribution of alleles for diploid organisms is determined through mating patterns and reproductive success when considering a closed, panmictic breeding population in which phenotypes arise out of developmental processes that begin with genotype formation. In other contexts, other measures for evolution are introduced (such as drift, mating patterns, and migration). More recently, measures relating to direct phenotype-to-phenotype transmission have been introduced when considering organisms that can emulate, imitate, or learn from the phenotypic state of other individuals.

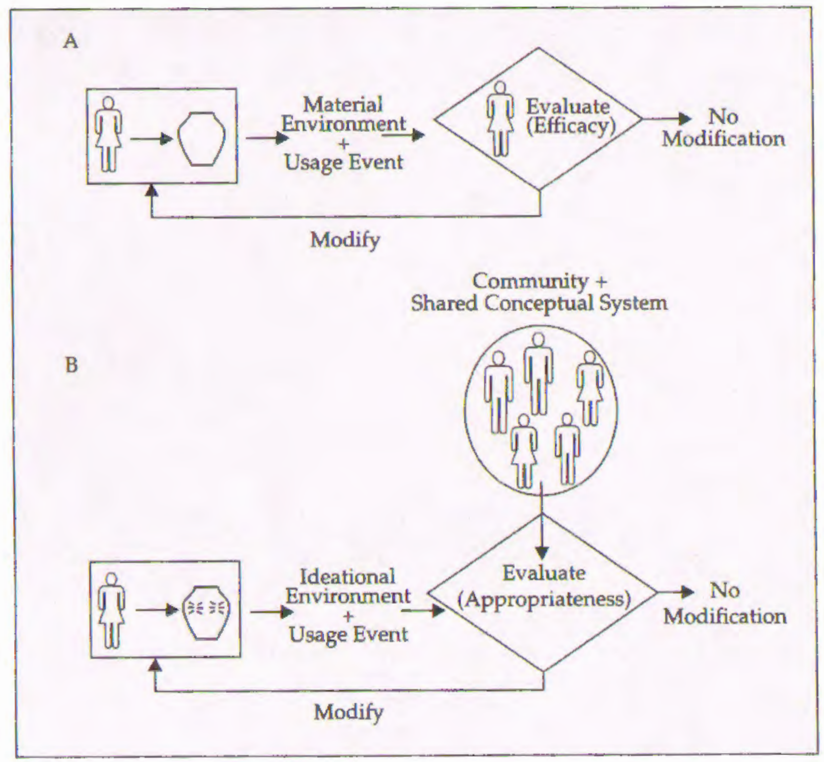
Hence, any measure of evolution that takes into account phenotypic variation and frequency distributions at the phenotypic level need not have a corresponding measure at the allelic/genotypic level. Instead, in this situation evolution is measured by phenotypic change driven by selection defined in terms of phenotypic transmission through learning/imitation. In brief, there is no "right" measure for what constitutes selection in the abstract; a measure (or set of measures) needs to be identified and grounded in the processes that underlie temporal change in the patterning and structure in the data brought forward for analysis.

Functional Traits: Phenomenological Measure of Fitness

The frequency distribution graphed in Figure 10.1 typifies a functional trait that does not arise directly from individual fitness values, but from decisions made by users and artisans regarding both production and use

of artifacts in the performance of activities. As discussed above, the latter provides feedback from the phenomenological/material domain with regard to the efficacy of doing a task with the current form and properties of the artifact (see Figure 10.6 A). Users, when faced with the choice between continuing to use a dull tool and resharpening the tool, will most likely opt for the latter when the perceived cost (in terms of time and energy) of using the dull tool outweigh the cost of resharpening the tool. That decision may or may not have reproductive fitness implications. For example, a hunter-gatherer group can have a population size stabilized by feedback from foraging costs if the latter sufficiently increases the likelihood for a woman to make a decision to delay or abort a pregnancy (Read and LeBlanc 2003).

Figure 10.6: (A) Selection for a functional trait (schematically indicated by lack of design on the pot) triggered by usage of the artifact and evaluation by the user of the efficacy of using the artifact/pot. (B) Selection for an isochrestic or truncated trait (schematically indicated by the pottery design) through usage of the artifact, but where selection is through a community of users/artisans who evaluate the appropriateness of the design in the context for the event that has taken place



Under these conditions, change and innovation may take place with respect to artifact materials and forms; but if a stabilized population size is maintained through fertility reduction, then the shift to a new artifact form does not always translate into increased individual fitness measured through reproductive success—otherwise the population would be growing and not stable. Yet archaeological evidence indicates that for a period of several thousand years, for example, the population size of Tasmania remained essentially constant due to carbohydrate shortage (Read 2006 and references therein). Nonetheless, changes did take place in the types of lithic artifacts that were produced, such as the introduction of thumbnail scrapers. It appears that Tasmanian women made reproductive decisions based on resource availability that led to a stabilized population size in the manner modeled by Read and Leblanc (2003). Since the artifact changes did not affect carbohydrate shortage as a limiting factor for population size, evolutionary changes took place in artifact form without the latter being driven by differential reproductive success.

Lack of change in reproductive fitness values does not negate an evolutionary argument for change in artifact form, but simply identifies the fact that individual users and artisans make selective decisions in terms of efficacy. These decisions may affect the frequency distribution of trait values regardless of whether the changes also affect reproductive success. For functional traits, we may postulate as a first approximation that decisions are likely to be directed toward increasing efficacy in the use of artifacts when there is feedback from the phenomenological/material domain regarding costs that relate to the time, energy, material suitability, and so on of using a particular type of artifact for the task at hand.

That we are cognitively constituted to make decisions in the direction of increased efficacy requires an argument based on natural selection since our cognitive capacities that bear on how we make decisions had to arise through a combination of mutation and natural selection. But once those cognitive decision-making processes are in place, we need no longer invoke individual fitness as a proximate explanatory mechanism. Instead, we may properly refer to those cognitive decision-making processes as the basis for selection and then explore the consequences of that kind of selection on the patterns we may observe in our data. To the extent that decision making is in the direction of increased efficacy, and assuming users and artisans have had sufficient time to explore the relevant artifact space with regard to efficacy in doing the task at hand, we are led to the conclusion that the frequency distribution for a functional trait will be similar to the frequency distribution shown in Figure 10.1 (Read 2005b).

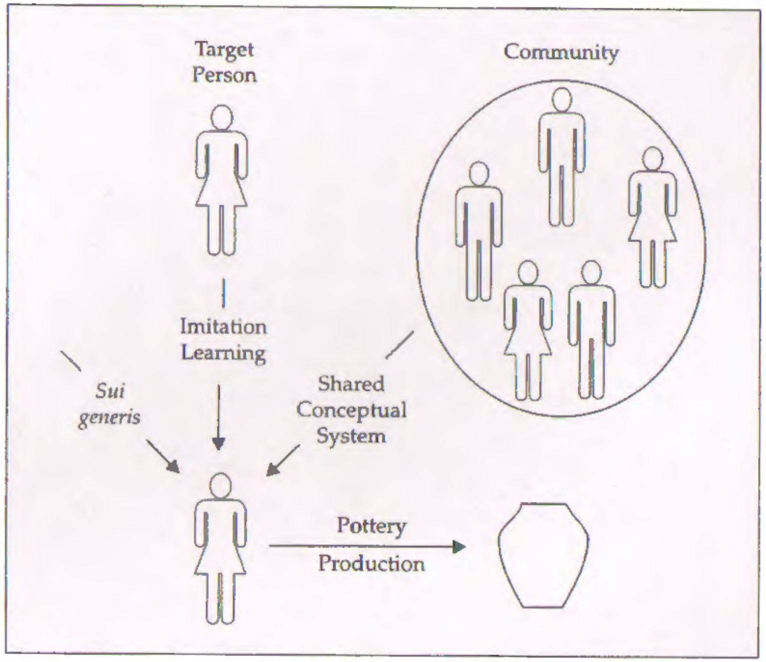
Stylistic Traits: Ideational Measure of Fitness

Once we recognize that selection may arise directly from decision making by users and artisans, it is conceptually a small step to widen the basis for decision making to include ideational—in addition to material—considerations. The need for so doing arises empirically since the frequency distribution patterns for isochrestic and truncated traits (see Figure 10.1 B and C) are neither subsumed under functional nor neutral traits. Both distribution patterns identify that selection has taken place since each pattern indicates that only a portion of the possible range and frequency of trait values actually occurs on artifacts. In both cases, the pattern is not consistent with constraints on trait values introduced through decision making based on feedback from the phenomenological/material domain. These patterns, however, are consistent with decision making at an ideational level that takes into account what can happen when artifact production and usage occur in a social context that provides feedback to the individual user regarding the evaluation made by other artisans/users of variant stylistic trait values (see Figure 10.6 B).

As discussed above, there is no single modality for selection acting on the several ways that collective artisan knowledge may become available to the individual artisan (see Figure 10.7). Convergence to a single mode can occur through imitation, where both the propensity to imitate and the selection of a target for imitation may have arisen through biological evolution. However, the evolutionary consequences of imitation need not be congruent with evolution driven by reproductive fitness (Boyd and Richerson 1985). In addition, imitation is not the only modality (and may not even be the most important modality) through which convergence takes place. More broadly, an individual becomes enculturated simply by virtue of the fact that birth and growth take place in a cultural milieu in which the developing individual is engaged in inferential learning about one's cultural environment through interaction with other individuals (see Figure 10.4, top right side). Just as we do not choose to learn a language as we physically develop from birth, we equally do not choose to learn culturally appropriate ways of acting or behaving but learn these inferentially through interaction with other individuals as we cognitively develop from birth. Imitation may be involved in the form of a role model in some cases, but what we are absorbing through enculturation is more complex than simply learning a specific behavior or set of behaviors, just as understanding a language involves more than transmitting vocabulary words from one individual to another.

Though one can construct a model for the transmission of artifact characteristics based on an assumption such as "each individual contacts

Figure 10.7: Three sources for knowledge used in artifact production: self-generated, imitation of a target individual, and interaction within a community of artisans and users



another individual chosen at random from the population" and then probabilistically "adopts whatever variant the contacted individual happens to carry" (Neiman 1995:10), it is a peculiar starting point for modeling transmittal of artifact traits since it assumes that artisans are not part of a social community.[17] If the intent of the modeling were just to provide a baseline condition that could be used to measure the degree of patterning introduced by more realistic assumptions about artifact production, the exercise would be useful (Shennan and Wilkinson 2001). More realistic assumptions would include various modes of selection affecting artifact production and usage arising from material, technical, social, and cultural dimensions.

But that does not appear to be the intent; the evolutionary archaeology program assumes that neutral traits are not merely the preferred definition of what constitutes style, but that style and function—as they define these terms—supposedly exhaust the domain of "culturally transmitted phenotypic variation" (Neiman 1995: 8). That assertion is an empirical, not a logical, claim and can be (and has been) falsified both through synchronic data on the form of frequency distributions for artifact traits

for artifacts from a restricted geographical range and time span (see examples earlier in this chapter), as well as by diachronic data on changes in the variety and frequency of traits, such as the diachronic pattern for incised pottery decorations considered by Shennan and Wilkinson (2001) for pottery vessels found in Neolithic settlements from Merzbachtal in western Germany.

Even though the division of traits into either stylistic (defined as neutral) or functional (defined as subject to fitness-based selection) is not tenable, the category of neutral traits is nonetheless valid and has empirical support, as discussed earlier in this chapter. In Rouse's terms, neutral traits are by and large attributes that are not modes; that is, they are aspects of an artifact idiosyncratic to the particular artisan who made that artifact. From this perspective, a neutral trait—such as the shoulder angle of the Scottsbluff points (Read 1982)—has a magnitude that is undirected from the viewpoint of the artisan and so a frequency distribution of trait values utilized by a single artisan would have an approximately uniform distribution over the range of possible trait values for that artisan.[18]

Evolutionary archaeologists have correctly pointed out that the observed frequency distribution for neutral traits will be affected by the learning network for transmission of information about possible trait values among artisans, but have assumed incorrectly that neutral artifact traits are transmitted in analogy with a genetically based, probabilistic model for both the structure of the learning network and the probability of transmission of information about trait values. Unlike genetic information, where transmission only takes place through a reproductive encounter by one individual with another individual of the opposite sex and where only one of the two units of information for trait values possessed by one individual can be transmitted when a reproductive encounter takes place, artifact traits are the material manifestation through artifact production of information/knowledge an artisan has about artifact production. That information can be shared among the members of a community of artisans and users directly through interaction among artisans and indirectly through the artifacts that are produced. If one potter introduces a unique design element as part of pottery making, that design element has the potential of being transmitted directly to another potter not just by an encounter between them, but indirectly by the other potter coming into contact with pottery having the unique design element. Transmission can also take place even more indirectly through a potter interacting with other individuals who have had contact with the potter or the pottery produced by the potter, and so on.

Under the neutrality assumption, the likelihood of the design element being transmitted to another potter through the potter becoming aware

(directly or indirectly) of a unique design element must be a stochastic event—with probability of occurrence independent of the particular artisan. Otherwise selection (though not necessarily fitness-based selection) is involved and the design element is not neutral. Hence transmission of the design element can be modeled as a simple diffusion process. Within a small community of interacting artisans, diffusion of knowledge can be rapid.

The neutrality assumption also implies that an artisan is indifferent to which one of the design elements known to the artisan will be employed when making an artifact; hence, the frequency distribution of design elements that are present in the artifacts produced by the artisan should converge to a uniform distribution over the design elements known to the artisan. For a community of artisans, neutral traits will be shared equally among artisans (as discussed above); the frequency distribution for each artisan will converge to the same uniform distribution, and for a neutral trait we should find a uniform distribution of trait values over the ensemble of artifacts produced by the artisans. Departure from a single uniform distribution will occur when considering artisan communities isolated from each other with respect to trait information diffusion. Thus, the data set brought forward for analysis needs to satisfy the Well-Defined Data criterion; that is, the data set should be partitioned into homogeneous subsets.

By forcing a two-way categorization of traits as either functional (selection driven by differential fitness of the artisans) or neutral (not subject to selection), evolutionary archaeologists have defined away any possible consideration of the way "material culture forms a set of resources, a symbolic order in practice, something drawn on in political relations, activated and manipulated in ideological systems" (Shanks and Tilley 1987b: 116). Equally problematic, however, is the other extreme claim that "to understand material culture is to accept it as stylistic cultural production" wherein "function is virtually redundant" (p. 97) and hence can be ignored.

Neither of these polar positions adequately takes into account the fact that artifact production involves instantiation in material form of multiple conceptual systems that incorporate both stylistic and functional dimensions. An artisan does not mechanically produce an artifact according to a mental template of trait-ideas, transmitted in analogy to transmission of the genetic basis for phenotypic traits; nor does the artisan construct a communication system analogous to the production of texts. Instead, he or she implements concepts about artifact production that draw upon a variety of sources, some relating to accumulated experience arising from interaction with the phenomenological domain and others to accumulated experience arising from interaction with other individuals that relates to the social and ideational domains.

What makes possible the multiplex nature of artifacts, both from the viewpoint of how they are produced and how they are used, is the incomplete specification of an artifact in any one of these domains. Even if we had an exhaustive specification of the functional constraints that guide the specific trait values imposed on an artifact during its production, we would not—except perhaps in exceptional cases—be able to construct the artifact from that information alone. Equally, a complete specification of the communicative, symbolic, and other, ideationally related aspects of artifacts and how these relate to the social and cultural system(s), contexts, and interactions in which the artisan is located as an active agent would not satisfy the archival criterion. Instead, it is in the interstices between what is specified by one domain through its material instantiation during the production of an artifact that material instantiations arising from the specifications of the other domain can reside and be implemented during artifact production.

For example, on one hand we can view a projectile point as involving material instantiation in the form of artifacts that are part of a design for action for the performance of a task, such as killing an animal with an implement in order to procure food for consumption (Ellis 1997; Knecht 1997). On the other hand, we can view the same projectile point from the viewpoint of the social context of its production embedded in a larger framework of interacting individuals that brings into play the conceptual and social basis for the interacting individuals to form a cohesive social unit in which individual interests are acted upon. But this already raises a series of questions, each of whose answer(s) may have an impact on the form and characteristics of an artifact produced in accordance with the multiple kinds of action that may involve a particular artifact.

For example, on the functional and phenomenological side, there is the question of how the animal will be killed—through injury to a vital organ, strangulation, exhaustion, drowning, shock and massive bleeding, or some other way of inducing death? Each of the latter may entail a different choice of material, form, and other characteristics of the artifact that will be used to carry out the stated action with its desired outcome. Strangulation may require a flexible, rope-like object that can be tightened around the neck of a quarry to restrict its oxygen intake. But that kind of artifact works poorly for introducing injury to a vital organ. The latter requires a device that can both penetrate through the outer parts of the animal and then into a vital organ. Penetration of the outer parts of the animal requires that the tip of the implement be made of material that can withstand the impact forces required for penetration without shattering the tip before it reaches the vital organ (Titmus and Woods 1986; Flenniken and Wilke 1989). Penetration requires that sufficient energy be

imparted to the implement so that it will penetrate into the animal, which entails design decisions taking into account the size and sharpness of the penetrating tip (Frison 1973, 1976; Van Buren 1974; Frison and Zeimens 1980), which relates in turn to constraints imposed by the material from which the tip is made and the energy required to penetrate through the body into a vital organ with a particular kind of implement.

The energy that can be transmitted to the implement is constrained by the means for energy transfer, which until recently depended upon muscle activity and the biomechanics and dynamics of the human body. Transfer of energy into power of penetration could be direct through the implement being held while it pierces into the animal or indirect through propelling the implement from the hunter to animal being hunted, each of which relates to different hunting strategies. Propelling the implement introduces aerodynamic design considerations that affect the mass, symmetry, and shape of the implement (Christenson 1986) in conjunction with design constraints related to the means for propelling the implement.

What we observe and categorize as a "projectile point" (or "jar," "bowl," "storage basket," etc.) is not simply a form that can be dissected into a series of traits, but a design that brings together a strategy for action (Kehoe 1966; Nelson 1997; Smitsman et al. 2005)—including assessment of risk (Bamforth and Bleed 1997; Elston and Brantingham 2002)—that constrains, to varying degrees, the material and form, say, of a projectile point such as (1) shape, sharpness, and angle of the tip for penetration; (2) form of the projectile base for hafting to a shaft used both for energy transfer and for aerodynamic stability; (3) weight, and symmetry of the projectile point; and (4) rigidity and hardness of material to maintain structural stability upon impact for penetration into the animal (Read 1987; Ellis 1997; Knecht 1997). Of these dimensions, the first gives rise to a modal value; the second limits the dimensions of the projectile point base but does not lead to modal values; the third limits the range of possible forms but does not specify a particular form; and the fourth relates to the technology for the implementation of the other dimensions. In effect, the functional constraints have transformed an initial, largely unspecified design space into a more specified design space (in the sense of specifying the relevant dimensions for the space) and have provided boundaries for the regions in this design space that satisfy the functional constraints. Let us call this reduced design space the *functional design space*.

Within this functional design space, the other aspects of the projectile point (which we refer to collectively as style) further limit the design space to a low-dimensional space with restricted regions within which the artisan locates the projectile point that is being produced. Some of the dimensions from the functional design space will now be given modal values (such as the side curvature of the Scottsbluff points) that further reduce the dimensionality within which variability—in the form of target values—can occur during production. The final design space for the projectile point may also have dimensions that are neutral; any value within the range of acceptable values for this dimension is satisfactory from both a functional and a stylistic viewpoint (such as the base shoulder angle for Scottsbluff points and the size of the san points).

Technology, mode of production, and design space come together in the production of an artifact in the manner identified in the *chaîne opératoire* approach to artifact analysis. Though the artifact is a single object, it is composed of different dimensions, each with its own "logic" for how that dimension is implemented and how dimensions may interact. A projectile point is not simply a certain form, but a form arising out of the manner in which technology of production, artifact material, and design are all brought to bear and the sequence of steps that are employed to bring these different dimensions and design considerations into fruition in the form of the finished artifact. A pottery object is not simply a vessel with a morphological form that may or may not be decorated, but a form whose construction is guided by the method of working the clay (e.g., modeling, coiling, or molding), the changing plasticity of the clay as the clay dries, and how these relate to the condition of the clay—as well as the steps in the morphological construction that intersect with the manner in which the design/decoration is constructed (Krause 1984).

Based on both Iron Age pottery from Phalaborwa, South Africa, and ethnographic observations from potters making the same kind of pottery, Krause developed an ordered sequence of formal rules that specify the steps inferred for the manufacture of Iron Age pottery vessels by means of the modeling method of pottery manufacture; he then found that the rules apply equally to the pottery made by his informants, yet have enough specificity to distinguish pottery making by Eskimo groups (who also use the same modeling method for making pottery vessels but follow a different sequence of steps) from Bantu pottery manufacture (Krause 1984, 1985, 1990). Krause also worked out an ordered sequence of eight rules and a lexicon of seven design elements that would "generate any (from the simplest to the most complex) of the designs and design configurations observed in a sample of twenty thousand specimens" (Krause 1984: 642). Finally and most important, he devised the "inter-nesting of elements" from the two sets of rules "so that a single derivation may be achieved" that can "predict the sequence [as] to event and practice as it has been inferred from the sample at hand" (p. 643).

What the potters are learning in the process of becoming potters (whether Bantu potters today or potters from the Iron Age) is a multifaceted, multiconnected conceptual system underlying the manufacture of

pottery as a totality in which are expressed both functional constraints—what Krause refers to as "high-risk practices" such as innovation in morphological form for which "miscalculations entail a high-risk of product loss" (p. 648)—and stylistic expression that are low risk and for which "innovation and experimentation in decorative embellishment and ornamentation may proceed with little or no worry about product loss, albeit new decorations are subject to the *guiding force of social approval*" (p. 648, emphasis added). With that last comment, Krause has succinctly identified the crucial aspect of artifact change not taken into account by the evolutionary archaeologists: "the complex nature of the interaction between social strategy and artifactual variability and change" that leads to viewing "material forms as part of the central order of cultural construction, rather than as either so embedded in an 'immediate' relationship with the environment as to be virtually 'non-cultural', or analysed as 'art', and therefore as virtually autonomous" (Miller 1985: 4, 205).

11

Conclusions

Beyond Practical Typologies

Classification is both an implicit and explicit process. When we did fieldwork in the Chevelon Drainage in Arizona in the 1970s, artifact material was bagged in the field and brought to our field camp for initial sorting into major groupings such as lithics, pottery sherds, ground stone, and so on. Some of these groupings were divided further, such as pottery sherds separated into plain ware versus fine ware and lithic material into retouched flakes, debitage, and so on. Further separation would take place during the analytic phases of the work. The division into kind of material—pottery, lithic, ground stone, and so on—is normally taken for granted as part of the fundamentals of analyzing artifact material. Discussions of classification in the literature barely mention this kind of division by kinds of material, since it seems self-evident that pottery material and lithic material represent different domains of artifacts and a typology for lithics would be irrelevant for a typology for pottery. Historically, we find a division in the archaeological literature between lithic typologies and pottery typologies and individual archaeologists have often focused on one or the other kind of material when concerned with formulating typologies. Measurements made on artifacts also tend to separate between qualitative and quantitative measurements, with qualitative measurements being used more frequently with pottery typologies and quantitative measurements more often arising in the context of lithic typologies.

Though the division is commonplace and uncontroversial, nonetheless it is part of the process of forming a typology for artifact material and the division arises for reasons that relate more generally to the methods of constructing a typology when the divisions are less obvious. Pragmatically, we make the division by material because it works. One would be hard pressed to find an example of a site for which a division of artifacts

by materials such as clay, flint, wood, bone, reeds, and so on is not useful for the purposes of forming a typology. On the other hand, divisions within similar kinds of materials may or may not be relevant. Clays from different sources may, but need not, be relevant to the kind of pottery vessels that were made. Ground stone artifacts used in the same way may be made from different kinds of raw material, and so on.

As argued by Adams and Adams (1991), we can construct a typology by focusing solely on apparent differences among artifacts and how they seem to sort into coherent groupings that we refer to as types. But is the fact that it works sufficient? Or do we need to probe deeper and consider the reasons why it works? Typologies can "work" even if "illogical, inconsistent, arbitrary, and fundamentally unscientific" as Klejn points out for Krajnov's (1972) typology of stone battleaxes from Central Russia, for even though the types are "based neither on a definitive primary feature nor on a cluster of objective features," they "do distribute neatly between areas and according to Fat'ianov [Fatyanovo] groupings, cultural and otherwise (Krajnov, 1972, pp. 38–39 et passim)" (Klejn 1982: 32)—thus satisfying Krieger's requirement that types have time and space coherence. That a typology "works" is clearly not sufficient; at a minimum, we need to understand why it works.

The sorting by kind of raw material taken for granted in the field works because the differences in raw material relate to properties necessary for the intended uses to be made of the artifacts formed from those materials. An arrow point made out of clay will not be effective for killing animals and a cooking pot for use over a fire will not last if it is made of wood. The artisans and users of artifacts are aware of the properties of raw materials and use that knowledge to decide upon the material to be used in the production of an artifact, given the intended use of that artifact. When the differences in properties between two kinds of raw materials are small in terms of properties relevant to the intended use of the artifact, we would expect that less attention would be placed on the choice between the raw materials with regard to how the properties relate to the intended use of the artifact, and instead that other considerations—such as ease of access, quantity available, and so on—may be more important for the choice of material.

Raw Material and Types

If we think of artifact production as historically beginning with the initial conceptualization of a particular kind of artifact (which already may be a complex process) and then eventually leads into routinized production

of the artifact (whether by individual artisans or in the context of some kind of workshop), concern with the relationship between the properties of materials and the intended use of the artifact are likely to be more pronounced in the earlier stages of this sequence. As production becomes more routinized, the choice of materials may also become standardized and the underlying reason for that choice may become less apparent to artisans. For example, when doing fieldwork among the !Kung san, we asked why they had changed from making arrow points from bone to arrow points made from fence wire. The typical answer was that this is the way other men made their arrow points, not that the characteristics of wire served better either for making or for using points with poison on the arrow shaft. Nonetheless, we can assume that at least in some stage of the process leading to a new kind of artifact, a conceptual mapping takes place that links the properties of materials to the conditions that must be satisfied for the artifact to be used in its intended manner:

Intended Use → Required Properties (mental conceptualization) → Material Choice

For example, if the intended use of the artifact is to cut or scrape another substance, then the intended use leads to the conceptualization that the artifact must be made out of a material with greater hardness than the substance that is to be cut or scraped, and it must have sufficient structural coherence—as a material—to reasonably retain its form under the forces that will be generated by the activity. Choice of material will be constrained by the conceptualized properties required for the intended task.

Intentionality and Types

To put it another way, kinds of artifacts—at least since the advent of modern *Homo sapiens*—arise out of intentionality and not simply by happenstance trial and error. This is not to say that trial and error is not part of invention. The properties of materials and how they relate to the effectiveness of objects for doing tasks can be determined through trial and error. However, this is of a different character than the random change of biological evolution, for in the case of artifacts the source of change—the producer of the object that is to be subjected to change—and the user of that object may be the same individual (or if not the same individual, they may interact with one another). In contrast to natural selection, selection by users of artifacts is immediate and based on direct experience with the artifact: whether it performs as desired and whether

its performance is satisfactory—and if it is not, how it might be changed to achieve the desired performance. Selection operates through evaluation of performance against what is expected or desired, and change operates through modification that might be part of an attempt to improve the performance of the artifact when used for its intended purpose. Selection is thus at a conceptual level through evaluation made by the user of how an artifact performs in terms of the performance that was desired or expected. Performance can be multifaceted and may be based on considerations as diverse as effectiveness in functional usage or accuracy in conveyance of symbolic information.

As easily as we speak of the material performance of an artifact used to modify objects in the material world, we can also speak of the symbolic performance of an artifact in social interaction. Artifacts are produced for a purpose and are evaluated in terms of that purpose. Artifacts are modified or changed based on the intended purpose and the performance that is desired. To consider artifacts solely as material objects to be categorized ignores the underlying processes that are responsible for the patterning in the material objects that we are trying to capture through the construction of a typology.

The type—it needs to be emphasized—is not the group of artifacts, but the class determined by the patterning the objects in the group seem to share in common. For example, Scottsbluff points share a common shape and can be distinguished clearly from other kinds of projectile points on the basis of that shape. Scottsbluff points do not grade into other types of points (contra Ford 1954), but instead constitute a distinct shape class that distinguishes them from the shape classes of other projectile points. As a class, they satisfy the internal cohesion/external isolation criterion with regard to the class members. Thus, the type, Scottsbluff Points, is a valid construct. Similarly, types of southwestern pottery (or pottery from whatever region) may be identified initially on the basis of a group of pottery objects that share commonality with respect to patterning of attributes, but the type is based on the shared pattern and is not a description of the pottery objects that are instances of that pattern.

The type, rather than the artifact, analytically becomes a unit; and for the type to be a unit, it must be the case that the artifacts grouped under the type are—from the viewpoint of the artisans and users of the artifacts—substitutable for one another. As White et al. (1977) comment with regard to indigenous categorization of stone tools by the Duna of New Guinea, "[A]n *aré* [unretouched flake] is either an *aré kou* [unretouched flake that can be hafted] or it is not. Categories or things *are seen as unitary and internally undifferentiated*. They are based upon the recognition of perceptual invariants" (p. 387, emphasis added).

Types of Patterning and Type Definitions

More formally, a type definition is based on patterned combinations of (certain) attributes. We can make the following distinctions regarding how a type T is defined.

(1) Patterning is object specific and may be defined in terms of a set of qualitatively different characteristics $a_1, a_2, \ldots, a_n$ whose presence or absence is observable on individual artifacts: $T = f(a_1, a_2, \ldots, a_n)$ (read "T is a function of the attributes $a_1, a_2, \ldots, a_n$"). The type does not depend on first determining a reference population for its definition.

For example, the artifacts that we categorize as lithics, pottery, basketry, and so on, are minimally distinguishable in terms of the material used to make the artifact (e.g., a_1 = flint, a_2 = clay, a_3 = reed, etc.) and the material is object specific; hence, we do not need to use statistical analyses to assign individual objects to a material category. Further, types defined in this manner can be distinguished with regard to qualitative characteristics such as shape differences based on topological features—that is, based on absolute qualitative differences such as a_1 = a surface with no holes (e.g., a plate or a jar without a handle or a spout); a_2 = a surface with a single hole (e.g., a jar with a spout but no handles); a_3 = a surface and an appendage to the surface with a hole (e.g., a jar with no spout and one handle); and so on—or on qualitative geometric differences such as the number of corners in the outline of an object (e.g., a_1 = 1 corner [leaf shape point with rounded base]; a_2 = 2 corners; a_3 = 3 corners [triangular shape point]; and so on.[1] Absolute qualitative and geometric differences are not context specific and do not depend on first identifying an artifact dimension or variable for defining the qualitative characteristic. An object can be assigned to a topological or geometric type solely by reference to the characteristics of the object in question and does not require a reference population to identify the type.

(2) Patterning is object specific and may be defined in terms of a bifurcated quantitative variable V with attributes observable on individual artifacts: $T = f(V; a_1, a_2, \ldots, a_n)$. The type does not depend on first determining a reference population for its definition, but the bifurcated variable V is context specific.

For example, notching on a projectile point is potentially a continuous dimension varying from 0 millimeters depth and we can measure the depth of notching. In fact, points rarely have shallow notches and so

degree of notching is bifurcated into two modes: a_1 = not notched or a_2 = notched.[2] In general, bifurcated quantitative variables are conceptualized as one state versus another state and not via the degree to which a state is present on an artifact. The modes are a transformation of a quantitative variable to a nominal variable. The attribute state can be observed on an individual artifact and so a reference population is not needed to define a type using a bifurcated quantitative variable.

(3) Patterning is only discernable by reference to a population P of artifacts and a quantitative variable V and also depends on specification of the process giving rise to patterning: $T = f(V; m_1, m_2, \ldots, m_n; P; Pr)$, where P is the reference population, Pr is the process through which artifacts are produced, and V is the variable (or variables) whose values over the population are the observations through which patterning is discerned and $m_1, m_2, \ldots, m_n$ are the modes for the variable V inferred from the patterning that has been discerned.

Examples would include types based on nominalized dimensions where type differences are based on properties, such as bimodality of a frequency distribution of a variable measured over a specified population of artifacts or distinct clusters in a scattergram plot of two (or more) quantitative variables. This could include differences within a qualitative shape category that are then patterned at a quantitative level through different size categories for the same shape. The quantitative pattern is both variable and population specific. Bimodality for one dimension need not entail bimodality for other dimensions. By its definition, bimodality is patterning in the aggregate and hence is population specific.

Item (3) includes a process as part of the type definition, since specification of an underlying process is needed to account for the form of the patterning observed for measurements taken over artifacts made in accordance with a normative value (Biskowski 1997). Artifacts have measurement values that reflect both the production process for the artifacts and a normative value that may be guiding the artisan in the production of artifacts. While we may interpret the central tendency of the measurements as an estimate of a normative value when the data set is homogeneous with respect to a single production process and a single normative value, the dispersion and the shape of that dispersion are also part of our etic specification. The latter relates to the process (or processes) through which artifacts are produced; hence, type specification also involves the process(es) giving rise to the nominalized quantitative dimensions we have discovered through our analysis.

Cultural Types are Discovered

Each of the analyses of artifacts discussed here—projectile points from 4VEN39, pottery from the Niederwil site, end-scrapers from Castanet A and Ferrassie H, and decorated bowls made by the Tewa and the Towa—demonstrates that it is possible to distinguish groupings of artifacts that have cultural salience; that is, each analysis has identified cultural types and not just empirical types. This means that connecting an empirically distinguishable group of artifacts with a cultural type is straightforward when the criteria for division of the data set can reasonably be interpreted as reflecting choices made by artisans in the production of artifacts.

At the purely qualitative level, topological differences in pottery objects are a consequence of a potter's decision about the kind of pottery object that he or she will produce. A bowl produced by the potter differs topologically from a jar with a spout by virtue of the potter's decision regarding the kind of pottery object he or she is making; hence, the etic, topological distinction has emic implications. We do not know what was in the mind of the potter when he or she made a bowl rather than a jar with a spout, but we do not need to know what was in the potter's mind. The fact that a collection of pottery objects can be divided into bowls versus jars with spouts is not due to our imposition of categories on pottery objects, but arises from the fact that the potters made topological distinctions among the objects they produced. The difference between a bowl and a jar is not happenstance, but depends on the action of the potter when forming a pottery object.

A similar comment applies for projectile points that can be distinguished by shapes used repeatedly across time and through space. An Elko corner notched point differs from a Cottonwood triangular point not because of our choice of what attributes to measure (though whether we notice the difference may depend on the attributes we have selected to measure), but because of the shape imposed by a flintknapper when making a projectile point. We discover the difference in shape; it is not imposed by us.

Similarly, the widespread tendency in southwestern pottery for temper to be of one type of material, but not a mix of materials, is due to choices made by potters when preparing clay for making pots. Those choices may relate to how the physical properties of the clay affect the effectiveness of the pot when it is used as intended, but that is part of the overall sequence of choices and decisions involved as an artisan goes from raw material to finished object—as has been made evident through the *chaîne opératoire* approach to modeling the production of artifacts (see Figures 3.2 and 7.1). Whether the potter uses sand temper or sherd temper (but not both) simply because it is his or her understanding of the

proper way to prepare clay for a particular kind of pot, or whether the potter is aware of—and acts in response to—the properties of the fired clay arising from one kind of temper or the other, is not critical. Instead, critical is the fact that a continuous dimension has been bifurcated. We discover the bifurcation; we do not create it.

Or when we find that the Cottonwood triangular points from 4VEN39 have a bimodal and nonoverlapping width, we have discovered a pattern imposed on the projectile points by the flintknappers. They have chosen not to make projectile points with widths that would, nonetheless, make for perfectly good projectile points from a functional viewpoint. We did not construct the bimodality through our analytical choices, but instead we discovered it as we explored different variables and the shape of the frequency distribution for these variables. We can plausibly interpret the bimodality as representing normative concepts about point width since the same pattern occurs throughout the site and through time—thus the relevance of Krieger's argument for relating types to time and space. Hence, there must have been shared notions regarding the width of these points throughout the time of occupation of this site.

Types, in the sense of culturally salient types, are discovered. To claim otherwise is to assume that in the data brought forward for analysis, qualitative differences, bifurcated quantitative variables, and nominalized quantitative variables do not exist. If it truly were the case that types are not (or cannot be) discovered, then we would simply form a single data set consisting of all artifacts and devise a universal set of measures to be applied equally to all the artifacts (see O'Brien and Lyman 2003 for an attempt to do so with projectile points).[3] Yet there is no archaeologist who does not initially sort lithics from pottery from organic tools from textiles, and so on. That sorting already admits the role of discovery: we discover that the artisans made distinctions in the kind of raw material used with respect to the artifacts they produced. Lithic tools differ from pottery objects, organic tools, and textiles in fundamental ways. Artifacts are structured according to raw material by virtue of the actions taken by the artisans. Whenever we sort artifacts by qualitative differences such as shape classes that do not grade into each other, we are discovering differences imposed by the artisans and users of those artifacts. But why should we stop with qualitative variables?

Patterning and structure introduced by the artisan are also part of quantitative variables, such as bifurcated or nominalized quantitative variables, when we discover the restriction of a potential continuum to only portions of that continuum. In the case of quantitative dimensions, it follows that we are not free to simply select whatever attributes we might deem to be of interest for the purpose of identifying types, but we need

to discover those dimensions that were relevant to decision making by artisans: "[T]hose peculiarities of vessels . . . occur as a result of the choice of the craftsman making the thing in question. . . . In describing the vessel by a list of attributes, *we are aiming to reflect each instance of choice* [by the craftsman]" (Marshak 1970: 25, as quoted and translated in Klejn 1982: 263–264, emphasis added). Nor are we free to nominalize (or ordinalize) a quantitative dimension in whatever manner we see fit as a way to construct an imposed, paradigmatic classification—that is, a classification composed of what Klejn (1982) has called *conditional types*—for then we are imposing our etic distinctions in lieu of the emically valid distinctions already embedded in the data brought forward for analysis.[4]

Klejn is one of the few archaeologists who have examined systematically the rational behind kinds of types—conditional, empirical, and cultural types—and how these relate to the more inclusive forms of organizations through which we group together ensembles of sites. With respect to the conditional types making up a paradigmatic classification (see note 4 for an example), he concludes that they "are condemned to remain conditional. It is impossible in principle to break through to the cultural meanings of the distant past by means of conditional types . . . the impossibility of an adequate substitution—without loss of cultural information—*of actual, culturally significant boundaries* by those selected arbitrarily" (1982: 268, emphasis added).

With respect to empirical types, Klejn observes, "[O]ne must be aware that the empirical exposure of the correlation of elementary properties in archaeology, however technically refined and complete, cannot by itself conduce to real cultural types. . . . [O]ne of the fundamental principles of archaeology [is] . . . the impossibility of the spontaneous integration of real cultural types of the past from the mass of elementary, empirically observed properties of archaeological materials" (1982: 267). He then goes on to elaborate, "With any integration of empirical types from elementary properties which is not guided by the introduction of *additional knowledge from the cultures level*, the cultural significance of types and properties must remain indefinite" (1982: 270, italics added). In effect, Klejn is arguing that any form of analysis unguided by our understanding of the relationship between the ideational/cultural and the material domain as it relates to artifact production—the motivation for the *chaîne opératoire* approach to artifact analysis—will fail to uncover patterning induced through culturally mediated behavior. We can, however, uncover this patterning through our analysis of the material remains of past societies by taking into account properties of cultural systems (as has been shown in the previous chapters).[5]

Klejn concludes that cultural types can only be discerned from a "top down" approach predicated—as he stipulated—on "additional knowledge from the cultures level," but makes this conclusion only because he was not aware of the possibility discerning cultural types from a "bottom up" analysis, as laid out in the preceding chapters. At the time he wrote *Archaeological Typology* (primarily in 1973–1974), analysis aimed at identifying empirical types meant using either Spaulding's conceptually incorrect use of statistical methods to determine cultural types through (nominal) variable association or object-clustering methods based on the invalid assumptions of numerical taxonomy. He did not know about the discovery methods discussed here that are grounded in "additional knowledge from the cultures level."

The discovery process is complex due to the nature of archaeological data. We begin with a palimpsest that is a compilation of multiple decision processes that bring together a variety of considerations underlying the production and use of artifacts and eventually leading to the assemblage analyzed by the archaeologist. Analytical methods, especially quantitative analytical methods, are constrained by homogeneity assumptions that require our data set to be dissected by precisely the dimensions our analysis is aimed at delineating when we want more than just numeric description from our methods. We classify and form types not simply as a means to organize a body of data, but as a way to identify the processes that have structured our data and thereby make apparent what lies beneath a palimpsest in the form of an assemblage formed by us through our surveys and excavations.

Our interest in identifying types lies not in the act of classifying per se, but in the information provided through the act of classifying. The justification for identifying and organizing types into a typology lies in whether our types and typology reasonably reflect the processes that produced the patterning we have identified. Types are real when they are formed in accordance with the patterning found by methods sensitive to the processes that are responsible for the structure we discern in the data we bring forward for study.

When production-structuring processes are guided by the cultural/ideational domain of producers and users that affect the decision processes involved in the production and use of material items, we can speak of cultural types. A cultural type may have multiple time and space boundaries for the instantiation of its defining characteristics.[6] Different types may have their own characteristic time and space boundaries, as may be seen in seriation diagrams for different types in the same region. These boundaries are not known a priori and yet analytic methods depend on sorting data according to these boundaries and types—the double-bind problem discussed in Chapter 8. The analytical sequence of sorting data first with qualitative dimensions and then applying quantitative methods addresses the double bind problem through the assumption that quantitative norms based on continuous dimensions are applied to qualitatively distinct artifacts. The Narrow/Wide distinction applies, for example, to the triangular, concave-based points at 4VEN39, but not to all lithics found at that site. A second way to address the double-bind problem is through initially restricting data sets to contexts, such as a single assemblage or a distinctive portion of an assemblage, under the assumption that a single assemblage is contained within, and does not straddle, a culturally salient space and time boundary.

The effectiveness of the methods discussed here for identifying patterning displayed in artifact material due to the processes that archaeologists want to identify and then explicate can be measured by the results that we obtain. The analyses presented in Chapters 8–10 (and a similar analysis based on utilized flakes [Read and Russell 1996]) illustrate how we can distinguish groupings reflecting the artisan's decision and production processes. These groupings and their inferred cultural types can serve as a firm basis for additional and more extensive research aimed at understanding and explicating the processes—both diachronic and synchronic—that structured the material remains of past human societies.

Appendix

Most clustering algorithms proceed agglomeratively by first assigning each object in the data set to a group of size one and then recursively forming a new, larger group from two existing groups based on a group similarity measure, until all objects are members of a single group. Clusters are distinguished by the groups defined at some step in the agglomerative procedure—that is, by a stopping rule for the agglomerative procedure. The stopping rule is generally applied to the agglomerative procedure as a whole, though Whallon (1990) has shown by example that more acceptable clustering results are obtained when stopping rules are specific to different "branches" in the clustering process. Choices among similarity measures for objects and groups and stopping rules for the agglomerative process are based on assumptions about the form and structure of clusters. Different clusters can be identified for the same data set depending upon the choice of a clustering algorithm. More problematic, though, than different clusters being identified for the same data set is the invalid convergence assumption underlying the rationale for using clustering methods based on unweighted variables.

Clustering algorithms presume a set of n variables (qualitative and/or quantitative) $\{X_1, X_2, \ldots, X_n\}$ are to be measured over a set S of m objects. The n variables determine an n-dimensional Euclidean space in which each artifact may be represented by a point. Similarity of one artifact to another is generally assumed to be measured by the closeness of one point to another in this space, where closeness might be measured by Euclidean straight-line distance, city block distance, or some other distance metric.

Clustering algorithms are used to determine coherent groups based on the erroneous assumption that as more variables or characters are measured, the analytically determined groupings will converge on structure embedded in the data matrix that can be described as "internally coherent/externally isolated" groups. Sokal and Sneath (1963: 111–118) provide the rationale for this assumption. However, the converse is more likely. As more variables are introduced to increase the variety and exhaustiveness of the characteristics being measured for the objects in question, it is *less* likely that convergence will take place and *more* likely that the clustering procedure will fail to find valid clusters embedded in the data (see Figure 5.3).

By "clusters embedded in the data" we mean that there is a set of variables satisfying the subdivision criterion discussed in Chapter 8:

> Subdivision Criterion: *A set S of objects will be said to be objectively subdivisible into* n *subgroups* $S_1, S_2, \ldots, S_n$, *if for any pair of subgroups* S_i *and* S_j, $i \neq j$, *there is some dimension* D *such that either (1) if the dimension* D *is represented with qualitative attributes, then objects in* S_i *share one (or more) attributes and objects in* S_j *share a different attribute(s) for the dimension* D; *or (2) if the dimension* D *is represented with one (or more) metric variables,* V, *then the pair of subgroups* S_i *and* S_j *will have (at least) a bimodal distribution with the objects in* S_i *forming one mode and the objects in* S_j *forming the other mode in the measurement space determined by the variable(s)* V.

Because the property P need not be the same for all pairs of subgroups S_i and S_j, strictly speaking, we should refer to property P_{ij}, but we will not do so for simplicity in notation. By a property P is not necessarily meant a value on a single, directly measurable dimension, but possibly a construct based upon several dimensions. For simplicity, we will assume that property P is based on metric variables.

The subdivision criterion differs significantly from the numerical taxonomy construct of polythetic groupings. Numerical taxonomy methods presume that similarity between entities should be based on the degree of commonality over a fixed set of variables, each of which is measured over all entities in S. In contrast, the subdivision criterion allows both for different properties to be used for subdividing a subset of S (thus encompassing Whallon's idea of different stopping rules) and for different sets of variables to be used when subdividing S into subsets (thus allowing for a taxonomic structure based on branch specific sets of variables for the subdivision criteria).

Typically, similarity between objects O_a and O_b in the data set S is expressed as some monotonic function of a distance measure $d(a, b)$ between these two objects. We will consider the case where the distance metric d is Euclidean distance squared:

$$d(a, b) = (x_{a1} - x_{b1})^2 + (x_{a2} - x_{b2})^2 + \ldots + (x_{an} - x_{bn})^2, \tag{1}$$

where x_{ai} (x_{bi}) is the value of the ith variable X_i for object O_a (O_b).

Let property P be represented by a k-dimensional space determined by the variables, $X_1, X_2, \ldots, X_k$, $k \leq n$, so that when the data points are projected into this k-dimensional space, subgroups satisfying the "internal cohesion/external isolation" criterion for clusters may be distinguished. We further assume that P cannot be represented within a j-dimensional space, $j < k$. We now assume that our data set S can be subdivided, using the subdivision criterion, into r distinct subsets, $S_1, S_2, \ldots, S_r$, satisfying the "external isolation/internal cohesion" property (see for example, Figure 5.2 D, where $k = 2$ and $r = 3$). A histogram for the distance measures $d(a, b)$ computed for every pair of objects in S will have

a multimodal distribution, with degree of overlap of nodes inversely related to the isolation of one group from another.

Now suppose that in addition to the variables $X_1, X_2, \ldots, X_k$, we also have variables $X_{k+1}, X_{k+2}, \ldots, X_n$, each of which has the same distribution for each S_i, $1 \le i \le r$, as for S; for example, each variable has the same unimodal distribution, say $N(\mu, \sigma^2)$, over S_i as it has for S. This could correspond to the situation where the set $\{X_i\}$, $1 \le i \le k$ is not known in advance and the researcher has used the set of variables $\{X_j\}$, $1 \le j \le n$, $k < n$, to measure the objects in question in an exhaustive manner. We further assume, for simplicity, that each X_j, $k+1 \le j \le n$ is independently distributed with regard to X_i, $k+1 \le i \ne j \le n$—that is, $Cov(X_i, X_j) = 0$, $k+1 \le i \ne j \le n$.

Let x_{ah} (x_{bh}) be the value of the variable X_h for the object O_a (O_b), $1 \le h \le n$ in S. For the objects O_a and O_b the distance measure,

$$d(a, b) = (x_{a1} - x_{b1})^2 + (x_{a2} - x_{b2})^2 + \ldots + (x_{an} - x_{bn})^2 \tag{2}$$

based on all n variables is composed of two parts:

$$d'(a, b) = (x_{a1} - x_{b1})^2 + (x_{a2} - x_{b2})^2 + \ldots + (x_{ak} - x_{bk})^2 \tag{3'}$$

and

$$d''(a, b) = (x_{ak+1} - x_{bk+1})^2 + (x_{ak+2} - x_{bk+2})^2 + \ldots + (x_{an} - x_{bn})^2, \tag{3''}$$

so that

$$d(a, b) = d'(a, b) + d''(a, b). \tag{4}$$

Note that $d'(a, b)$ is the distance between objects O_a and O_b in the space defined by $X_1, X_2, \ldots, X_k$.

Now consider what happens to (1) the mean, or expected, value for each variable and (2) the variance of the squared distances when the original set of variables $\{X_1, X_2, \ldots, X_k\}$ is augmented by the variables X_j, $k+1 \le j \le n$. To do so, define the random variables D_{ij}, D'_{ij} and D''_{ij} over $S_i \times S_j$ by letting $d(a, b)$, $d'(a, b)$ and $d''(a, b)$ be the value taken on by the random variable D_{ij}, D'_{ij}, and D''_{ij}, respectively, when applied to a pair of objects O_a in S_i and O_b in S_j. Now compute the expected value $\mu_D = E[D_{ij}]$, for D_{ij}. Then from equation (4) it follows that

$$\mu_D = E[D'_{ij}] + E[D''_{ij}]. \tag{5}$$

If i, j are both subset indices for objects in a single subset (so that $i = j$), then $E[D'_{ij}]$ is the mean distance within that subset based on the variables $X_1, X_2, \ldots, X_k$ (these variables determine the property P through which the subset is distinguished) and μ_D is the mean distance within that subset when all n variables are taken into consideration. Thus, the mean distance within a subset will be increased by the amount $E[D''_{ij}]$ when the original set of variables is augmented by the variables $X_{k+1}, X_{k+2}, \ldots, X_n$.

Similarly, if i and j are subset indices for objects in different subsets (so that $i \ne j$), then $E[D'_{ij}]$, the mean intergroup distance, will be increased by the amount $E[D''_{ij}]$ when the original set of variable is augmented. But by the independence of the X_j and the assumption about the distribution for each of the variables X_j, $k+1 \le j \le n$, it follows that for these subset indices, $E[D''_{ij}]$ will have the same value whether the objects come from the same or different subsets.

The effect of the additional variables, then, is to increase the expected values for intragroup distances and intergroup distances by the same amount. Consequently, the addition of the variables $X_{k+1}, X_{k+2}, \ldots, X_n$ does not change the difference between the expected values based on intra- and intergroup distances and therefore *reduces* the relative magnitude of the differences between these values.

Next, from the assumption regarding the independence of the variables X_i, $k+1 \le i \le n$, it follows that for subsets S_i and S_j,

$$Var(D_{ij}) = Var(D'_{ij}) + Var(D''_{ij}). \tag{6}$$

If we further assume, for simplicity, that the variables $X_{k+1}, X_{k+2}, \ldots, X_n$ each have identical variance, then we may write:

$$Var(D''_{ij}) = (n-k)\sigma^2, \tag{7}$$

where σ^2 is the variance, for fixed h, of the values $(x_{ah} - x_{bh})^2$ obtained for all object pairs O_a and O_b from subsets S_i and S_j, respectively, $k+1 \le h \le n$. Now within each subset S_i, each variable X_j, $k+1\, j \le n$, has the same variance as for the whole data set S, so when variances are computed using only the objects in a single subset S_i, the value for $Var(D'_{ii})$ will also be equal to $(n-k)\sigma^2$.[1] Both the intragroup and the intergroup variances of the distances are increased by the same amount, $(n-k)\sigma^2$, when the original set of variables is augmented by the variables X_i, $k+1 \le i \le n$.

Hence (a) the difference in magnitude between the mean intragroup distances and the mean intergroup distances has remained the same; (b) the difference of the one as a proportion of the other has decreased; and (c) the variances have increased by the quantity $(n-k)\sigma^2$. Consequently, the histogram of interpoint distances will be altered in the direction of less distinct multimodality. Therefore, the effect of the added variables is to reduce discrimination among the subgroups. If the reduction is sufficient, multimodality will be swamped and the subgroups will become indistinguishable. We thus conclude that the convergence assumption, in general, is false.

Clustering algorithms will not converge, then, on embedded clusters as more variables are measured simply as a way to ensure that the initially unknown dimension(s)—along which the clusters are distinguishable—are included within the measurement space when the additional variables have a distribution independent of the cluster structure. The latter is likely to occur when additional variables are included since the dimensions along which clusters may be discerned are initially unknown. Loss of the cluster structure can occur with the addition of a single variable independent of the cluster structure as can be seen by comparing Figures 8.6 and 8.13.

Notes

Chapter 1

1. In a taxonomic classification (see Figure 1.4 for an example), not all attribute combinations necessarily lead to distinct classes, whereas in a paradigmatic classification all possible attribute combinations are considered to be relevant (Whallon 1972). A contingency table, for example, has the structure of a paradigm. A paradigm can be considered to be a special case of a taxonomy in which no variable is excluded as one traces through a pathway in the taxonomy.
2. Gould comments that "no reliable or consistent relationship exists between the archaeologist's classification . . . and the Aborigine's own way of classifying these items" (p. 120). However, this only applies to an "archaeologist's classification" that has a paradigmatic structure. A taxonomic structure matches the Aborigine's emic classification and is the kind of classification that characterizes so-called intuitive classifications. The emic classification need not have linguistic labeling for the distinctions made by the users of the artifacts such as hafting small—but not large—*purpunpa* since our interest is in how conceptual categorizations are expressed through material differences in artifacts and not in the pattern of linguistic labeling (or lack thereof) for those differences.

Chapter 2

1. The same quandary arises with Taylor's distinction between an empirical type and a cultural type (Taylor 1948). The former is based on what whatever properties of artifacts are distinguished by the researcher and the latter are based on properties of artifacts that were distinguished by the makers and users of the artifacts.
2. The type/artifact relationship became circular in South's definition that "*attributes* are those observable criteria . . . by which a ceramic type has been defined" and "*a type* refers to pottery defined by one or more key attributes…" ([1977] 2002: 201).
3. Ewen (2003) has noted the important role of functional types in historical archaeology due to the work of Stanley South ([1977] 2002) and how they

have been used to "detect patterns of regularity and variability in the site's assemblage that might be used inductively to generate statements of theory" (Ewen 2003: 73–74).
4. Strictly speaking, the population mean, standard deviation, and covariance only characterize a joint normal distribution. For a homogeneous data set, where the variation in measurement values is due to a single process structuring the phenomena of interest, the data are likely to have approximately a joint-normal distribution (see Chapter 8).
5. Dunnell applied the ideational/phenomenological distinction more broadly than just to the distinction between a group and the class for which the group members are instances of the class, but not always with clarity (Spaulding 1974).
6. The intellectual lineage going from Rouse to Dunnell is evident in this quote and acknowledged by Dunnell in the preface to the book.
7. The pair "decorated"/"nondecorated" form a contrasting pair much as +1 and –1 form a contrasting pair with the meaning of the symbol "+" or "–" arising from the way these two units relate conceptually to one another via the product equations $+1 \times +1 = +1$, $+1 \times -1 = -1$, $-1 \times +1 = -1$ and $-1 \times -1 = +1$. Similarly, the oppositional pair "decorated"/"nondecorated" would have been embedded into a larger system of meanings if the opposition "decorated"/"nondecorated" is a culturally salient opposition for the pottery in question and "nondecorated" is not simply an etic "wastebasket" category.
8. Formally, a taxonomy can be converted into a paradigmatic classification by adding a dimension value, "other," to each dimension as needed and then taking the intersection of the augmented dimensions. Pragmatically, though, the "other" category may not have any meaning in the ideational domain upon which the dimensions and their values are based.

Chapter 3

1. Sackett's comment that "there should be no residue of formal variability left unexplained once style and function have themselves been totally accounted for" (Sackett 1977: 370) is thus falsified empirically. Style, for Sackett, seems to be the societal "choice" of one value for some dimension or aspect as opposed to some other value (p. 370), whereas function refers to the "cultural life" of an artifact and includes the "societal and ideational realm" as well as the "material realm of technology and economics" (p. 370). But not all aspects of an artifact can be subsumed under style or function in the sense that these terms are used by Sackett.
2. In a similar vein, some researchers have distinguished between "intentional" and "mechanical" variables (Sackett 1966, 1977; Costin and Hagstrum 1995).
3. For example, Hole and Heizer define an artifact type to occur when "several attributes combine or cluster with sufficient frequency or in such distinctive ways that the archaeologist can define and label the artifact and can recognize it when he sees another example" (1973: 110).

4. See Colton (1941) for a description of the prehistoric method of pottery making in the Southwest.
5. By "recognized" we do not necessarily mean conscious awareness, but recognized in the broader sense that the patterning of some property across a relevant corpus of pottery objects indicates that the value for that property has consistently affected decisions (implicitly or explicitly) made by the artisan in the production of pottery. This will be discussed in more detail in Chapter 8.
6. The fact of color differences in pottery from two different regions need not imply that a conceptual transformation is involved. Mogollon and Anaszai pottery wares differ in that the former have a brown color and the latter have gray and white colors, but the color differences may simply be due to difference in iron content in the clay of the two regions where the pottery was produced (Wilson et al. 1996).
7. For example, in a recent reanalysis of Hohokam red ware pottery from the Salt River Valley, Abbott and Walsh-Anduze (1995) argue that change in production of wares was not regionally uniform—as had been previously assumed (e.g., Gladwin et al. 1937; Schroeder 1952; Haury 1976)—but involved changes in ware production that partly reflected location of raw materials (p. 95) and population interaction (p. 107) coupled with an overall temporal shift from micaceous schist temper with a yellow-red slip (Gila Red ware) to sand temper with an orange slip (Salt Red ware) in the Phoenix basin during the Classic Period. As a consequence, no single kind of ware—neither Salt Red ware nor Gila Red ware, nor variant wares such as Squaw Peak Red ware (Cable and Gould 1988) and Wingfield Red ware (Doyel and Elson 1985; Abbott and Gregory 1988)—characterizes the wares found contemporaneously in the valley during the transition. Since wares are defined by two kinds of transformations (clay properties and surface transformations), there is no a priori reason to assume that a ware acts as a unit; rather, the degree to which change in one transformation is matched by a change in another transformation must be empirically demonstrated in the absence of adequate theory delineating the relationships between these two kinds of transformations. As worked out by Abbott and Walsh-Anduze for the Hohokam in the Salt River Valley, the two transformations are not tightly coupled across the region and through time.

Chapter 5

1. The shift is obscured, however, by Spaulding's incorrect assumption that variable association was a means to measure attribute association. The former shares with the methods of numerical taxonomy the notion that patterning is to be found over an aggregate and not on individual objects, whereas attribute association may be observed on individual artifacts.
2. Topological shape differences cannot be transformed smoothly when changing one shape into a different shape. A smooth transformation can in principle be carried out by stretching or shrinking the boundary of a form—including the material contained within the boundary—without tears or breaks, such as changes that could be made on a two dimensional form drawn on a sheet of rubber through stretching or compressing the rubber. For example, Cottonwood Triangular projectile points and Desert Side-notched projectile points are topologically equivalent since the notch in the latter point type can be eliminated by a continuous deformation of the notch.
3. The nonoverlap in the modes of the distribution satisfies the idea that "the method for delineating a type is to locate the area of discontinuity that separates members of opposing types" (Chang 1967: 80).
4. The same indeterminancy arises with other clustering methods for these data.
5. In a simlar vein, Cowgill asserts, "I think if one works with due regard for its limitation ... [numerical taxonomy] can be quite useful" (1984: 54) but offers no guidelines for when the assumptions of numerical taxonomy are satisfied, erroneously assumes only the choice of algorithm is at issue, and ignores the fact that the conceptual foundation for the numerical taxonomy methods is invalid (as mathematically proven in the Appendix). Apparently, Cowgill does not consider inability to distinguish between obvious shape differences—such as leaf shape convex base points versus triangular shape concave base points—when using all of the morphological variables as measured (regardless of clustering algorithm) to be a serious problem with numerical taxonomy methods. Instead, he favors the supposedly "much more successful average-linkage algorithm" (p. 54) despite the fact that Christenson and Read (1977) reported an unacceptable 20% error rate when using average-linkage clustering. In contrast, even naive students distinguish the two shapes with no error, as discussed in the text. Cowgill's misguided attempt to reduce the issues regarding the conceptual foundation of numerical taxonomy methods to simply a dispute over algorithms has recently been revived by Kwon (2005). In his extensive classification of Kaya ceramics conducted as part of his study of change in Kaya polities between 0 and 600 AD, Kwon cites Cowgill (1984) to justify uncritical use of clustering algorithms.
6. The site was excavated by H. T. Waterbolk and J. D. van der Waals (Waterbolk and van Zeist 1967, 1978). The pots were measured by J. P. de Roever and the measurements were reported in Whallon (1982) with her permission.
7. An eigenvalue in the context of principal component analysis can be interpreted as a measure of the amount of variability that occurs along the axis representing a principal component. When standardized variables are used (as is typically the case), each variable has variance equal to 1 and so an eigenvalue of 1 corresponds to a principal component with the same amount of variability along its axis as occurs with a single variable. Because the goal of dimensionality reduction is to determine new dimensions (or axes) that account for most of the variability in the data, principal components with an eigenvalue < 1 are often discarded since such a principal component "captures" less variability than occurs with one of the original measurements.
8. Since the data brought forward for analysis are heterogeneous, it is difficult to interpret what is being measured by the principal components. The variability that determines the principal components includes variability within any

grouping satisfying the internal cohesion/external isolation criterion as well as differences between groupings, along with the confounding effect that valid groupings may not be based on the same variables.

Chapter 6

1. The arbitrariness of the blade/flake distinction can be seen in scattergram plots provided by Honegger of length versus width of flakes/blades for which there is but a single cluster of objects with no discontinuities (2001: 89, Figure 36).
2. In the absence of discontinuities, nominalizing an otherwise continuous variable is doubly problematic. First, it confounds etic with emic categorizations. Second, it requires making judgment calls as to when a measurement fits into a nominalized category. For example, Beck and Jones (1989) classified lithics from the Catlow area in the Steen Mountains of southeastern Oregon into types on the basis of edge damage. One of the variables measured the edge shape as concave, straight, or convex as an imposed geometrically based nominal distinction on the continuous variable, edge curvature. Not surprisingly, they found considerable disagreement among researchers in their categorization of edge shape. As noted by Fish (1978), making a nominal division on a continuously varying dimension can lead to error rates as high as 40%. Similar problems occur with pottery typologies that require distinctions—such as the size of sherd temper or the degree of smudging—be nominalized, but not on the basis of discontinuities in a quantitative dimension. Though they do not recognize the problem with using nominalized variables without discontinuities, Whittaker et al. (1998) find error rates as high as 50% for these "subtle temper gradations" (Whittaker et al. 1998: 157) when classifying Sinagua pottery.
3. From a material perspective, all objects are three dimensional. From a conceptual perspective, objects may be zero dimensional (a point), one dimensional (a "line"), two dimensional (the outline of an artifact), or three dimensional—according to what aspects of the material object are conceptually relevant (Pigeot 1991).
4. The system of measurement is also redundant since six measurements are made on the biface, but the default assumption of symmetry and the assumption that the side of the biface is a simple, convex curve imply that the outline can be represented with four measures: chord length, maximum height of curvature above the chord, distance to the maximum height for the arc making up one side of the biface, and maximum width.
5. The "center" can be defined in a number of ways, such as the center of mass if we assume the outline encloses a surface with uniform density. Since there is no reason to presume that the artisans produced lithic artifacts with respect to a cognized "center," there is no reason other than pragmatic utility to choose one particular definition of a center.
6. If the C curve cannot be adequately represented by these three measurements, it may be necessary to use the method discussed earlier where the curve is embedded into a Cartesian coordinate system and a mathematical function is constructed that fits the curve. The question of adequate representation is less a mathematical/statistical judgment than an archaeological one when considering whether an exact representation or a "smoothed" representation is adequate for the task at hand.
7. Identification of a utilized edge is not problematic (personal experience of the author). Experimental work on producing use wear on flakes has shown about an 80% accuracy rate for identification of utilized edges (Odell and Odell-Vereecken 1980).

Chapter 8

1. Though it would be more appropriate to consider the excavated projectile points as a sample from a population of projectile points, this requires a foray into statistical inference procedures that relate sample data and summary sample measures to population properties. These sampling procedures are not directly relevant to the methods developed in this chapter. Statistical inferential procedures are ultimately needed, though, since most often the data brought forward for analysis are a sample from the population of interest. However, inferential procedures do not apply until after the population of interest has been delineated, which in turn does not depend upon using statistical inferential procedures. We can therefore assume, without loss of generality, that the excavated projectile points are the population of interest. This allows us to focus on methods for relating data patterns to an artifact typology that will be derived from the characteristics of the artifacts brought forward for analysis.
2. The construction of histograms involves a number of technical matters relating to grouping of values that will not be discussed here. Any introductory statistics book has a detailed discussion of constructing bar charts and histograms. The facility with which charts may be made with programs such as Microsoft Excel™ precludes the need to make charts by hand.
3. In case of ties for the most frequent value, each of the most frequent values is a mode. This differs from the notion of a multimodal distribution based on the shape of a histogram with more than one peak,where the peaks need not be of the same height.
4. Outliers do not have a good technical definition since identification of a value as an outlier depends on its location in relationship to the rest of the histogram, the process by which the data were generated, and whether the population is a representative sample of all the values that can be produced by the process(es) through which the data were generated. We will use a "rough-and-ready" notion of an outlier as being a value that is so obviously outside the pattern for the rest of the histogram. that a statistical measure of its status as an outlier is not needed for verification of its status as an outlier.
5. Although there are statistical methods for deciding if an observation is outside a posited pattern for the data displayed in a histogram, these depend upon

having data sampled from a well-defined population in accordance with a statistically designed sampling regime. For archaeological data, the sources of bias and error between a population of archaeological interest and the sample data recovered by the archaeologist are so many that only patterning with a clear signature can be reliably discerned. Hence, differences in patterning should be qualitatively evident and not depend solely on statistical inferential procedures for verification. Consequently, classical statistical hypothesis testing will only occasionally be employed here. In the current example, we can see by inspection that the projectile point at 75 degrees is not part of the general trend in the data. We confirm the point as an outlier by considering whether its properties support the conclusion that it is distinct from the other projectile points. In fact, the point in question appears to be a blank and not a finished projectile point.

6. Any empirical collection C of artifacts produced by an artisan in accordance with the value d^* as the intended value for the dimension D of the artifact in question will have a mean value μ_C for that dimension and only by coincidence will it be the case that $\mu_C = d^*$. Equality only occurs by coincidence since the empirical collection C is happenstance in the sense that the artisan might have produced more (or fewer) artifacts than is actually the case. Suppose the artisan had produced the empirical collection C* instead, with $\mu_C^* \neq \mu_C$. Then even if $\mu_C = d^*$, it follows that $\mu_C^* \neq d^*$ for the empirical collection C*. Hence, the mean value for the empirical collection of entities actually produced depends on the particular empirical collection the artisan happened to produce and cannot be assumed to be equal to d^*.
7. The sample standard deviation must be computed with the formula $s = \sqrt{\frac{\sum (x - \bar{x})^2}{n-1}}$ for the standard deviation estimator to be unbiased.
8. Procedures for estimating parameter values based on sample summary measures (called statistics in contrast with population parameters) will not be discussed here since estimation does not directly bear on how patterning "in the aggregate" relates to normative/culturally constrained properties of artifacts.
9. For example, for each of six potters from Dangawa, central India, the maximum diameters of $n = 100$ *divaniya* (oil lamps) have a unimodal, approximately normal distribution with almost no variation in the mean maximum diameter between potters (Miller 1985: Figure 10).
10. Properly speaking, the p value only applies to a target population for which the data in hand are a random sample. The relationship between the data in hand and a population of archaeological interest is complicated due to the factors that have intervened between the production of the pots by artisans and their recovery through excavation. The p value should be treated as a guideline and not a definitive value. In this instance, the p value suggests that the slight deviation of the intercept of the regression line from zero (see equations for lines in Figure 8.17) could be due to depositional and post-depositional processes and/or sampling effects.

Chapter 9

1. Of course, other possible reasons for the bimodality other than the action of the artisan must be rejected first. Bimodality in simple morphological dimensions, such as the width of an object, almost surely reflects decisions on the part of the artisans.
2. At the phenomenological level of artifacts as they actually occur in sites, the matter is more complicated. There are a variety of reasons why a particular artifact happens to be in a site; these mitigate against mechanically linking every attribute combination found on artifacts with a type from the perspective of the producers and users of the artifacts at the time the site was occupied. Some artifacts are brought in by trade and while an attribute combination on the artifact may represent a type in the locality where the artifact was produced, a trade good may be a "type" from the viewpoint of those receiving the trade item based on aspects of the artifact such as the locality from which it was obtained, its status as a trade item, and so on. Zeros also need to be treated cautiously: a zero may be due to sampling error and not to representing an attribute combination that never occurs.
3. In general, we cannot match a pattern of frequency counts to a unique process since we can form the same pattern in multiple ways if we allow for a type to be linked to several different processes. Even with a single process, the pattern of frequency counts could change when the process is done more intently if the mapping from intensity of an activity to frequency is not the same for all types involved in the same activity. Hence, any interpretation of patterning based on frequency counts needs independent corroboration.
4. Nonindependence of the variables could also be due to more than a single cell being over- or under-represented. Since a 2 × 2 table has df = 1, we cannot determine if more than one cell is over- or under-represented. Consequently, we begin with a more parsimonious hypothesis: the over- or under-representation is due to a single cell. Data other than the expected frequency counts would be needed to determine if the pattern of artifact type usage is more complex than just a single type being produced in greater or lesser quantity than would be expected, based on the frequency of the other artifact types.
5. See Christenson (1987) and Noah (2005) for examples using this method to analyze an $m \times n$ contingency table. The interation process can be done relatively simply when using computer-based statistical computations. The cell in question can be updated with its expected value, then updated with the new expected value, and so on, until the new expected values converge on a stable value for the new value for a cell. The same updating can then be done with another cell modified using the same procedure, including updating any previously modified cell.
6. Other applications of the log-likelihood models to archaeological data include Clark (1976), Hietala and Stevens (1977), Spaulding (1976, 1977), Graves (1981, 1994), Lewis (1986), Kohler and Matthews (1988), and Noah (2005).
7. In a different context, especially with pottery vessels, we might accept low frequency counts as types if there were evidence suggesting that the objects with low frequency counts are not simply sporadic objects.

8. Sackett (1966) interpreted the association of round with retouched with convergent as a mechanical consequence of retouching, such as might occur through usage and resharpening of an end-scraper (see also Dibble 1995). However, the data considered here suggest that convergent end-scrapers were functionally distinct from the parallel end-scrapers.

Chapter 10

1. Because we are concerned with how style and function relate to classification, we will exclude style viewed as the "characteristic manner of achieving some end" as in "Hopewellian and Mississippian 'styles' of ceramics" (Sackett 1977: 374), as well as style viewed as what is produced in "a specific time and place" (Sackett 1977: 370; see also Hodder 1990), including style as it relates to technology (Lechtman and Merrill 1977; Lemonnier 1986; Childs 1991).
2. While many definitions of style have been suggested (see review by David and Kramer 2001), there is no standard definition of what is meant by style (Bentley and Maschner 2001). Definitions such as "*formal variation in material culture that transmits information about personal and social identity*" (Wiessner 1983: 256), or Wobst's (1977) influential view of style as involving information exchange, confound what style may *do* with what style *is*. The definition offered by Shanks and Tilley that style is "the mode of existence of particular attributes of material culture arranged in a series, displaying regularity, and having specifiable conditions of existence in terms of the constraints placed upon discourse with a determinate set of social relations mediating and transforming the form in which those social relations are, alternatively, conceptualized, represented and misrepresented" (Shanks and Tilley 1987a: 155), simultaneously confounds design with style and a purported dynamics of social relations as *explanation* for style/design with what style *is*. The definition by David and Kramer that style is a "*potential for interpretation residing in those formal characteristics of an artifact that are acquired in the course of manufacture as the consequence of the exercise of cultural choice*" (2001: 172) accords with the frequency distribution concept of style developed in this chapter.
3. Miller (1985) provides an example of reconceptualization by the Dangwara of central India where "the *keliya*, a pot which is used only or water, is given only on ceremonial occasions and is always black" (1985: 148) even though black pottery is "associated with the secular domain" (1985: 146). This pot with its black color has been reconceptualized by them as appropriate for the particular ritual in which it is embedded, even though black pottery otherwise is the pottery of the secular (rather than the ceremonial) domain.
4. Wiessner (1985) almost makes the same point in her comment that "people compare their ways of making and decorating artifacts with those of others and then imitate, differentiate, [or] ignore" by comparing "their ways of making and decorating artifacts with those of others" (p. 161), but then adds the further qualification that "stylistic outcomes project positive images of identity to others *in order to obtain social recognition*" (p. 161). The italicized comment distracts by introducing intentionality unneeded for her more central observation regarding the importance of a social context of interaction for selection to occur with stylistic traits. The social context can also lead, she argues, to a space and time boundary when there is convergence to a single value (or a narrow range of values) and in doing so "stylistic behavior presents information about similarities and differences that can help reproduce, alter, disrupt, or create social relationships" (p. 161). This assertion is undoubtedly valid, but having consequences of this kind in the social domain is not a necessary condition for a trait to be considered stylistic.

5. The term *isochrestic* was introduced by Sackett (1982) in reference to "choices made by artisans, whether consciously or not, from a broad spectrum of equally viable alternative ways of achieving the same end" (Sackett 1986: 630). Whereas Wiessner linked style with social interaction, Sackett linked isochrestic to "craft traditions in which they have been enculturated as members of a social group" (p. 630). However, the latter distracts from Sackett's main point regarding selection from among alternative possibilities for achieving the same end. We will use isochrestic here as referring to the value to which there is convergence and leave to the side whether the underlying behavior leading to convergence is primarily social, as argued by Wiessner (1984, 1985); symbolic/identity construction, as argued by Shanks and Tilley (1987a; 1987b); or due to craft traditions or the like, as argued by Sackett (1982, 1986). In any of these cases, there is convergence to a single modal value and/or narrow range of values. How the convergence arose in the first place is relevant to the *interpretation* we place on that convergence, but not to the fact that convergence did take place.
6. In the absence of other criteria for determining if a trait with a unimodal distribution is isochrestic or functional, the distinction based on the pattern for frequency distributions brings us back to Krieger's argument regarding justification for a type vis-à-vis its spatial and temporal distribution. An isochrestic trait common to a number of groups will likely have different mean values for groups that are spatially and/or temporally isolated, whereas a functional trait should have essentially the same mean over different regions and time periods.
7. Any attempt to relate stylistic differences in lithic materials to culturally or socially distinguished social units has the same problem with lack of a simple correlation between a style boundary and a boundary for a social unit that arises with pottery artifacts.
8. The small sample sizes for some of the sites reduces the power of the t-test and only more extreme differences will be found to be significant, even should it be the case that the population mean bowl sizes are different among the sites being compared.
9. Although the trait value for a neutral trait is not emically specified, the pattern of idiosyncratic values can take on emic significance, as discussed by Wiessner (1983). In the case of the !Kung san, the individual characteristics of arrow points are linked to the artisan who made the arrow and identification of the arrow maker has cultural significance due to the raw meat of a hunted animal being distributed by the owner of the arrow (who need not be the hunter) that killed the animal (Marshall 1976).

10. We do not know the particular constraints that led one group to make points with a particular side curvature for Scottsbluff points and another widely separated group a different curvature, but if there were no constraints operating at the community level, we would expect artisans in the same community to make points with whatever side curvature is convenient as long as it does not affect the efficacy of using the points for hunting; hence, we would expect large variance in edge curvature. In contrast, making an artifact with both a target value for a trait and a small variance around that target value has the cost of obtaining the skills required for an artisan to successfully meet that goal each time an artifact is made. Obtaining skills circumvents what otherwise would be the cost of making many failed attempts to produce an artifact that meets the desired goal. For functional traits, the artisan costs are balanced by efficacy in the performance of a task with the artifact having that trait; for isochrestic traits, the cost must be balanced by social costs that might arise from whether an artifact is considered well made or properly made by other members of the community.
11. Wiessner does not provide data on possible interaction between the two individuals whose points make up the single peak in Figure 10.6. The peak could also be due to coincidence in the trait values imposed by each of the two artisans.
12. Similar comments have been made by evolutionary archaeologists with regard to functional and neutral traits (Lipo and Madsen 2001; VanPool 2001).
13. For example, Ramenofsky and Stefen assume that archaeologists should "import the theoretical package from biology" and the only problem in so doing lies in "reassembling it and adding key empirical components" so that they can "[create] units to describe the empirical variation of the human phenotype . . . [that] we measure archaeologically" (Ramenofsky and Stefen 1998: 15).
14. The "style = neutral traits" definition would relegate a neutral trait (such as the length of broken and resharpened projectile points) to style and would relegate to function the shape of !Kung san arrow points due to the form of the frequency distribution for shape when these points are considered in isolation (see Figure 10.3), yet would relegate the !Kung san shape pattern to style when the analysis includes the comparable G/wi and !Xo points since the latter have a different shape (see Figure 10.2). Neither implication is in accord with the way in which function and style have generally been used by archaeologists.
15. The evolutionary archaeology program has also been said to insufficiently take into account aspects of human systems such as the basis for—and purposefulness of—innovation, the intentionality and goal-directedness of behavior, differences in the mode of transmission of traits, and the organizational structure of social and cultural systems (Rosenberg 1994; Wylie 1995; Bettinger and Richerson 1996; Schiffer 1996; Spencer 1997; Boone and Smith 1998). All of this has been rejected by the proponents of evolutionary archaeology as stemming from criticisms that "misinterpret or miss critical aspects of evolutionary archaeology," along with a "failure to grasp how the tenets of Darwinism are conceived by evolutionary archaeologists to apply to archaeology" (Lyman and O'Brien 1998: 616).
16. Dunnell appears to confound individual fitness with group fitness when he considers " 'stylistic' . . . types to be neutral variants (i.e., variants whose phenotypic expression did not affect the fitness of the *population*)" (2001: xvi–xvii, emphasis added). However, other proponents of evolutionary archaeology clearly consider individual fitness to be the driving force for change in functional traits.
17. In contradiction to his probabilistic model for transmission of neutral traits, Neiman accepts the premise that "successful transmission of style in the context of pottery manufacture requires some form of *perduring* relationship between teacher and learner (e.g., Bunzel 1929; De Boer 1989)" (Neiman 1995: 28, emphasis added).
18. By the Law of Large numbers, the frequency distribution for a neutral trait will converge to a uniform distribution as long as the parameters for artifact production do not change; more artifacts are produced by an artisan; and each trait value has the same probability of occurrence when the artisan produces an artifact, independent of other characteristics of artifacts and/or quantity of different artifact types produced. In the short run, the empirical distribution could differ substantially from a uniform distribution.

Chapter 11

1. From a topological viewpoint, a jar with a spout and no handle and a jar with no spout and a single handle are not equivalent even though each has one "hole." The hole in the former case makes it possible to go from one side (commonly called the inside) to the other side (commonly called the outside) without traversing the boundary of the object (the rim of the jar). Thus, liquid poured through the spout goes from the inside to the outside of the jar without traversing the rim. In the second case, the hole only provides a pathway from one side to the other side of a surface appended to the object without traversing the boundary. The hole does not provide a pathway from the inside to the outside of the jar; liquid poured from a jar with a handle but not a spout must still pass over the rim.

   These topological differences are not merely a mathematical distinction but relate directly to conceptualizations about the functionality (or intended functionality) of objects, even if only at an implicit level. We are so familiar with differences in functionality associated with topological differences that they may seem commonplace and even trivial. Thus, we know from experience that a handle without a hole is hard to hold if the long axis of the handle is placed vertically since there is no way for a finger to "hook" the handle, as is possible when the same handle has a hole. Similarly, putting a hole in a handle with a horizontal long axis provides little advantage over the same handle without a hole. Though these observations may appear commonplace from a pragmatic viewpoint, differences in the degree of functionality of handles arise from topological differences and geometric placement of

handles that have been incorporated in the design of pottery and other objects with handles, and the latter affects the methods of artifact production. As Smitsman et al. have commented, "The topology therefore determines whether a particular constitution of a tool and target will be a means to an end" (2005: 134).

2. Whether a point is notched does not correlate with other characteristics of projectile points (Christenson 1987), so the notched/not notched dimension is independent of any other mode and is one of the few cases of a mode for which the choice of a modal value is statistically independent of the modal value for any other dimension on the artifact.
3. Consider what happens when a combined data set ignores possible division by differences in types. The projectile points from the Holocene era Hester site in Mississippi were combined and then stratified only by occupation level prior to statistical analysis, despite the presence of several projectile point types. For the combined data, no statistically significant change in the mean neck width of the point base across the four occupation levels was found (Burris 2006), regardless of the fact that change in neck width has been a chronologically sensitive dimension in other regions—for example, decrease in neck width for projectile points from southern Idaho (Fawcett 1998) and increase in neck width of Plains Small Side-notched points (Kehoe 1966) through time. However, re-analysis of the Hester projectile data reveals that the lack of change is an artifact of combining the points into a single data set. The combined data set obscures the significant increase in neck width for the Dalton points ($x_{level\ 4} = 17.6$ millimeters, $n = 7$; $x_{level\ 3} = 20.9$ millimeters, $n = 6$; $t = 2.65$, $p = 0.02$) when going forward in time from occupation level 4 to level 3—the only occupation levels in which the Dalton points occur. Other types in the site do not have a change in neck width.
4. Following arguments by Dunnell that types are "illusory, transitory configurations" and variation within a type is "imperfect expression in a contingency-bound world" (1986: 153, as quoted in Burris 2006: 11), Burris (2006) divided the points at the Hester site into an imposed 3 × 3 × 3 paradigmatic classification based on a three-part, arbitrary subdivision for each of the shoulder width, based height, and basal indentation ratio variables since traditional types allegedly "obscure patterns of continuous variation" (Shott 1996: 290, as quoted in Burris 2006: 6). Similarly, O'Brien and Layman advocate an imposed paradigmatic classification: "the analyst specifies which characters and character states to use. The intersection of character states defines the classes" (2003: 139). However, note 3 shows that "patterns of continuous variation" ascertained within the framework of traditional types may be hidden when the analyst uses an imposed, paradigmatic classification.
5. Of course, if one denies—or views as minimal—a causative role for the ideational domain with respect to the products of human behavior (e.g., Dunnell 1980; Lyman and O'Brien 1998; O'Brien and Lyman 2000), then whether empirical types can be related to cultural types is of no particular importance when the causal mechanisms for change are taken to be natural selection and drift. Yet O'Brien and Lyman comment, "The analyst selects dimensions . . . that appear to be relevant to some problem . . . that are used to sort specimens into internally homogeneous, externally heterogeneous classes. Thus, from the materialist view, historical change is rendered as alterations in the frequencies of *analytical*, not *natural*, kinds" (2000: 189). Either they are saying that "internally homogeneous/externally heterogeneous" classes are arbitrarily imposed, in which case the argument is circular, or the "internally homogeneous/externally heterogeneous" classes (or at least the groupings upon which the classes are defined) are discovered—but they reject the possibility (and implications) of the latter out of hand as an instance of discredited essentialism. They assume "natural kinds" are "inflexible units . . . that cannot change to incorporate an individual that falls outside the boundaries of the kind" (1996: 32) and thereby ignore the fact that the link between the ideational and the phenomenological domain is not isomorphic mapping, but instantiation; that is, artifacts are an instantiation through production of concepts and ideas that affect, but do not determine rigidly, what the artisan produces. Assume the triangular points from 4VEN39 have been produced under a normative contrast between a specific conception of Narrow versus Wide. Variation in width occurs due to the vagaries of flint knapping and the interests of the flint knapper; hence, the normative types, Narrow and Wide, are instantiated as two phenomenological groups of points with varying widths and all the vagaries that may be introduced when making a point that is an instance of what we mean by the types identified in the typology for 4VEN39 (see Figure 8.12). The normative values for what constitute Narrow versus Wide could have changed through time, but apparently did not for the points at 4VEN39; if they had, we would simply include the time-based trajectory for change in the normative values for Narrow and Wide as part of our type specification.
6. A Scottsbluff point, for example, has a characteristic shape with broad space and time boundaries for its instantiation in the form of finished projectile points. As demonstrated by Read (1982), the tip angle had a normative value that likely reflected functional constraints and appears to have had a time and space boundary co-terminus with the time and space boundary for the Scottsbluff points. The curvature of the sides of the point, however, had several normative values, each with its own time and space boundary (though we lack data on how these different boundaries are interrelated). The shoulder angle was not normatively constrained and so may have had a space and time distribution pattern of angle values for which drift may have been the primary structuring process.

Appendix

1. This statement assumes that the population S and each of the subpopulations S_i is infinite. If not, equality may not hold but the thrust of the argument does not change.

References

Abbott, D. R., and D. A. Gregory. 1988. "Hohokam ceramic wares and types," in *The 1982–1984 excavations at Las Colinas: Material culture, vol. 4. Arizona State Museum Archaeological Series 162*. Edited by D. R. Abbott, K. E. Beckwith, P. L. Crown, R. T. Euler, D. A. Gregory, J. R. London, M. B. Saul, L. A. Schwalbe, and M. Bernard-Shaw, pp. 5–28. Tucson: University of Arizona Press.

Abbott, D. R., and M.-E. Walsh-Anduze. 1995. "Temporal patterns without temporal variation," in *Ceramic production in the American Southwest*. Edited by B. J. Mills and P. L. Crown, pp. 88–114. Tucson: University of Arizona Press.

Adams, E. C. 1991. *The origin and development of the Pueblo Katsina cult*. Tucson: University of Arizona Press.

Adams, R. M. 1940. Diagnostic flint points. *American Antiquity* 6:72–75.

Adams, W. Y., and E. W. Adams. 1991. *Archaeological typology and practical reality: A dialectical approach to artifact classification and sorting*. Cambridge, UK: Cambridge University Press.

Agresti, A. 1996. *An introduction to categorical data analysis*. New York: Wiley.

Ahler, S. A. 1971. *Projectile point form and function at Rodgers Shelter, Missouri*. Columbia: Missouri Archaeological Society.

Aldenderfer, M. 1998. Quantitative methods in archaeology: A review of recent trends and developments. *Journal of Archaeological Research* 6:91–120.

———. 2006. "Costly signaling, the sexual division of labor, and animal domestication in the Andean highlands," in *Behavioral ecology and the transition to agriculture*. Edited by D. J. Kennett and B. Winterhalder, pp. 167–196. Berkeley: University of California Press.

Allen, M. S. 1996. Style and function in East Polynesian fish-hooks. *Antiquity* 70:97–16.

Ammerman, A. J. 1992. Taking stock of quantitative archaeology. *Annual Review of Anthropology* 21:231–255.

Amsden, C. A. 1949. *Prehistoric southwesterners from Basketmaker to Pueblo*. Los Angeles: Southwest Museum.

Andrefsky, W. 2005. *Lithics: Macroscopic approaches to analysis*, 2nd edition. Cambridge, UK: Cambridge University Press.

Bamforth, D. B., and P. Bleed. 1997. "Technology, flaked stone technology, and risk," in *Rediscovering Darwin: Evolutionary theory and archeological explanation*,

vol. 7, *Archaeological Papers of the American Anthropological Association*. Edited by C. Barton and G. A. Clark, pp. 109–139. Washington, DC: American Anthropological Association.

Bar-Yosef, O., and S. L. Kuhn. 1999. The big deal about blades: Laminar technologies and human evolution. *American Anthropologist* 101:322–338.

Barton, C. 1988. *Lithic variability and Middle Paleolithic behavior. BAR International Series No. 408*. Oxford: British Archaeological Reports.

Barton, C. M., and G. A. Clark. Editors. 1997. *Rediscovering Darwin: Evolutionary theory and archeological explanation. Archaeological Papers of the American Anthropological Association*, vol. 7. Washington, DC: American Anthropological Association.

Bean, L. 1972. *Mukat's people: The Cahuilla Indians of southern California*. Berkeley: University of California Press.

Benfer, R. A. 1967. A design for the study of archeological characteristics. *American Anthropologist* 69:719–730.

Benfer, R. A., and A. N. Benfer. 1981. Automatic classification of inspectional categories: Multivariate theories of archaeological data. *American Antiquity* 46:381–396.

Bentley, R. A., and H. D. G. Maschner. 2001. Stylistic change as a self-organized critical phenomenon: An archaeological study in complexity. *Journal of Archaeological Method and Theory* 8:35–66.

Bettinger, R. L., J. F. O'Connell, and D. H. Thomas. 1991. Projectile points as time markers in the Great Basin. *American Anthropologist* 93:166–172.

Bettinger, R. L., and P. Richerson. 1996. "The state of evolutionary archaeology: Evolutionary correctness, or The search for the common ground," in *Darwinian archaeologies*. Edited by H. D. G. Maschner, pp. 321–331. New York: Plenum.

Binford, L. R. 1962. Archaeology as anthropology. *American Antiquity* 28: 217–225.

———. 1963. "A proposed attribute list for the description and classification of projectile points," in *Miscellaneous studies in typology and classification, Anthropological Papers No. 19*. Edited by A. M. White, L. R. Lesis, and M. L. Papsworth. Ann Arbor: University of Michigan Museum of Anthropology.

———. 1965. Archaeological systematics and the study of culture process. *American Anthropologist* 31:203–210.

———. 1977. "Forty-seven trips: A case study in the character of archaeological formation processes," in *Stone tools as cultural markers: Change, evolution and complexity. Prehistory and Material Culture Series No. 12*. Edited by R. V. S. Wright, pp. 24–36. Canberra: Australian Institute of Aboriginal Studies.

Binford, L. R., and S. Binford. 1966. A preliminary analysis of functional variability in the Mousterian of Levallois Facies. *American Anthropologist* 68:238–295.

Biskowski, M. F. 1997. Adaptive origins of Prehispanic markets in central Mexico: The role of maize-grinding tools and related staple products in early state economies. Ph.D. Dissertation, University of California, Los Angeles.

Bisson, M. S. 2000. Nineteenth century tools for twenty-first century archaeology? Why the Middle Paleolithic typology of François Bordes must be replaced. *Journal of Archaeological Method and Theory* 7:1–48.

Black, G. A., and P. Weer. 1936. A proposed terminology for shape classifications of artifacts. *American Antiquity* 1:280–294.

Bleed, P. 1986. The optimal design of hunting weapons: Maintainability or reliability. *American Antiquity* 51:737–747.

———. 2001. Trees or chains, links or branches: Conceptual alternatives for consideration of stone tool production and other sequential activities. *Journal of Archaeological Method and Theory* 8:101–127.

Bleed, P., and A. Bleed. 1987. Energetic efficiency and hand tool design: A performance comparison of push and pull stroke saws. *Journal of Anthropological Archaeology* 6:189–197.

Boëda, E., J.-M. Geneste, and L. Meignen. 1990. Identification de chaînes opératoire lithiques du Paléolithique ancien et moyen. *Paléo* 2:43–80.

Bonnichsen, R. 1977. *Models for deriving cultural information from stone tools. Mercury Series No. 60*. Ottawa: National Museum of Man.

Boone, J. L., and E. A. Smith. 1998. Is it evolution yet? A critique of evolutionary archaeology. *Current Anthropology* 39:S141–S173.

Bordes, F. 1961. *Typologie du Paléolithique ancien et moyen. Mémoire 1*. Publications de l'Institut de Préhistoire de l'Université de Bordeaux: Delmas, réédition CNRS 1988.

———. 1965. A propos de typologie. *L'Anthropologie* 69:369–377.

———. 1969. Reflections on typology and techniques in the Paleolithic. *Arctic Anthropology* 6:1–29.

Bordes, F., and D. de Sonneville-Bordes. 1970. The significance of variability in Paleolithic assemblages. *World Archaeology* 2:61–73.

Borillo, M. F. 1977. "Raissoner, calculer," in *Raisonnement et méthodes mathématiques en archéologie*. Edited by M. F. Borillo, F. de la Vega, and A. Guenoche, pp. 1–31. Paris: Editions du Centre National de la Recherche Scientifique.

Boyd, R., and P. Richerson. 1985. *Culture and the evolutionary process*. Chicago: University of Chicago Press.

Braithwaite, M. 1982. "Decoration as ritual symbol: A theoretical proposal and ethnographic study in southern Sudan," in *Symbolic and structural archaeology*. Edited by I. Hodder, pp. 80–88. Cambridge, UK: Cambridge University Press.

Braithwaite, R. B. 1953. *Scientific explanation: A study of the function of theory, probability and law in science*. Cambridge, UK: Cambridge University Press.

Braun, D. P. 1983. "Pots as tools," in *Archaeological hammers and theories*. Edited by J. Moore and A. Keene, pp. 107–134. New York: Academic.

Brew, J. O. 1946. "The use and abuse of taxonomy," in *Archaeology of Alkali Ridge, southeastern Utah*, vol. 21, *Papers of the Peabody Museum of American Archeology and Ethnology*, pp. 44–66. Cambridge, MA: Harvard University.

Brown, J. A. 1976. The southern cult reconsidered. *Midcontinental Journal of Archaeology* 1:115–135.

Bullen, R. P. 1975. *A guide to the identification of Florida projectile points*. Gainesville, FL: Kendall Books.

Bunzel, R. 1929. *The pueblo potter*. New York: Columbia University Press.

Burgess, R. J., and K. L. Kvamme. 1978. A new technique for the measurement of artifact angles. *American Antiquity* 43:482–486.

Burris, A. 2006. Defining an alternative typology for early Holocene projectile points from the Hester site (22MO569), Northeast Mississippi: A systematic approach. M.A. Thesis, Mississippi State University.

Cable, J. S., and R. R. Gould. 1988. "The Casa Buena Ceramic assemblage: A study of typological systematics and ceramic change in Classic Period assemblages," in *Excavations at Casa Buena: Changing Hohokam land use along the Squaw Peak parkway*, vol. 1, *Publications in Archaeology No. 11*. Edited by J. B. Howard, pp. 271–357. Phoenix: Soil Systems.

Carlson, R. L. 1970. *White Mountain Redware: A pottery tradition of east-central Arizona and western New Mexico. Anthropological Papers of the University of Arizona 19*. Tucson: University of Arizona Press.

———. 1982. "The polychrome complexes," in *Southwestern ceramics: A comparative review*, vol. 15, *The Arizona Archaeologist*. Edited by A. H. Schroeder, pp. 210–234. Phoenix: Arizona Archaeological Society.

Cavalli-Sforza, L. L., and M. W. Feldman. 1981. *Cultural transmission and evolution*. Princeton, NJ: Princeton University Press.

Chang, K. C. 1967. *Rethinking archaeology*. New York: Random House.

Chenall, R. G. 1967. The description of archaeological data in computer language. *American Antiquity* 32:161–167.

Childe, V. G. 1956. *Piecing together the past: The interpretation of archaeological data*. New York: Praeger.

Childs, S. T. 1991. Style, technology, and iron smelting furnaces in Bantu-speaking Africa. *Journal of Anthropological Archaeology* 10:332–359.

Christenson, A. 1986. Projectile point size and projectile aerodynamics: An exploratory study. *Plains Anthropologist* 31:109–128.

———. 1987. "Projectile points: Eight millennia of projectile change on the Colorado plateau," in *Prehistoric stone technology on northern Black Mesa, Arizona*, vol. 12, *Southern Illinois University Occasional Paper*. Edited by W. J. Parry and A. Christenson, pp. 143–198. Carbondale: Center for Archaeological Investigations.

Christenson, A., and D. Read. 1977. Numerical taxonomy, *r*-mode factor analysis and archaeological classification. *American Antiquity* 42:163–179.

Clark, G. A. 1976. More on contingency table analysis, decision making criteria, and the use of log linear models. *American Antiquity* 42:259–273.

Clarke, D. 1968. *Analytical archaeology*. London: Metheun.

Close, A. E. 1979. The identification of style in lithic artefacts. *World Archaeology* 10:223–237.

Cochrane, E. E. 2001. "Style, function and systematic empiricism: The conflation of process and pattern," in *Style and function: Conceptual issues in evolutionary archaeology*. Edited by T. D. Hurt and G. F. M. Rakita, pp. 183–202. Westport, CT: Bergin & Garvey.

Collins, M. B. 1975. "Lithic technology as a means of processual inference," in *Lithic technology: Making and using stone tools*. Edited by E. Swanson, pp. 15–34. The Hague: Mouton.

Colton, H. S. 1941. "Winona and Ridge Ruin, Part II: Notes on the technology and taxonomy of the pottery," in *Winona and Ridge Ruin, Museum of Northern Arizona, Bulletin 19*. Flagstaff: Northern Arizona Society of Science and Art.

Colton, H. S. 1946. *The Sinagus. A summary of the archaeology of the region of Flagstaff, Arizona*. Flagstaff: Northern Arizona Museum.

———. 1952. *Pottery types of the Arizona strip and adjacent areas in Utah and Nevada*. Flagstaff: Museum of Northern Arizona.

———. 1953. *Potsherds*. Flagstaff: Museum of Northern Arizona.

———. 1955. *Check list of southwestern pottery types. Ceramic Series No. 2*. Flagstaff: Museum of Northern Arizona.

Colton, H. S., and L. L. Hargrave. 1937. *Handbook of Northern Arizona pottery wares, Museum of Northern Arizona Bulletin, No. 11*. Flagstaff: Museum of Northern Arizona.

Cormack, R. M. 1971. A review of classification. *Journal of the Royal Statistical Society* 134:321–367.

Costin, C. L., and M. B. Hagstrum. 1995. Standardization, labor investment, skill, and the organization of ceramic production in late Prehispanic Highland Peru. *American Antiquity* 60:619–639.

Cotterell, F. C., and T. Deuel. 1990. *Mechanics of pre-industrial technology*. Cambridge, UK: Cambridge University Press.

Cowgill, G. 1982. "Clusters of objects and associations between variables: Two approaches to archaeological classification," in *Essays on archaeological typology*. Edited by R. Whallon and J. A. Brown, pp. 30–55. Evanston, IL: Center for American Archaeology Press.

Cox, D., and D. Hinkley. 1974. *Theoretical statistics*. London: Chapman & Hall.

Crabtree, D. E. 1972. *An introduction to flintworking*, vol. 28. *Occasional Papers of the Idaho State University Museum*. Pocatello: Idaho State University Museum.

Crown, P. L. 1981. Variability in ceramic manufacture at the Chodistaas site, east-central Arizona. Ph.D. Dissertation, University of Arizona.

———. 1990. "Converging traditions: Salado polychrome ceramics in Southwestern prehistory." Paper presented at the 55th Annual Meeting of the Society for American Archaeology, Las Vegas, Nevada.

———. 1994. *Ceramics and ideology: Salado polychrome pottery*. Albuquerque: University of New Mexico Press.

———. 1996. "Change in ceramic design style and technology in the thirteenth to fourteenth-century Southwest," in *Interpreting southwestern diversity: Underlying principles and overarching patterns, Anthropological Research Papers No. 48*. Edited by P. R. Fish and J. J. Reid, pp. 241–247. Tempe: Arizona State University.

D'Andrade, R. 2001. A cognitivist's view of the units debate in cultural anthropology. *Cross-Cultural Research* 35:242–257.

David, D. D. 1983. Why pots are decorated. *Current Anthropology* 29:365–389.

David, N., and C. Kramer. 2001. *Echnoarchaeology in action*. Cambridge, UK: Cambridge University Press.

De Bie, M. 1998. "Late Paleolithic tool production strategies: Technological evidence from Rekem (Belgium)," in *Lithic Technology: From Raw Material Procurement to Tool Production: Workshop No. 12 of the XIII International Congress of Prehistoric and Protohistoric Sciences*. Edited by S. Milliken and M. Peresani, pp. 91–95. Forli, Italy: M.A.C.

De Boer, W. R. 1989. "Interaction, imitation, and communication as expressed in style: The Ucayali experience," in *The uses of style in archaeology*. Edited by M. Conkey and C. Hastorf, pp. 82–104. Cambridge, UK: Cambridge University Press.

de la Vega, W. F. 1970. "Quelques propriétés des hiérarchies de classifications," in *Archéologie et calculateurs*. Edited by J. C. Gardin, pp. 329–340. Paris: Editions du Centre National de la Recherche Scientifique.

Débenath, A., and H. L. Dibble. 1994. *Handbook of Paleolithic typology, Volume One: Lower and Middle Paleolithic of Europe*. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Decker, D. 1976. "A typology for the Chevelon flaked lithic implements," in *Chevelon archaeological research project, Monograph II*. Edited by F. T. Plog, J. Hill, and D. Read, pp. 92–106. Los Angeles: Department of Anthropology, University of California, Los Angeles.

Deetz, J. 1967. *Invitation to archaeology*. New York: Natural History Press.

Dibble, H. L. 1984. Interpreting typological variation of Middle Paleolithic scrapers: Function, style, or sequence of reduction. *Journal of Field Archaeology* 11:431–435.

———. 1987. The interpretation of Middle Paleolithic scraper morphology. *American Antiquity* 52:109–117.

———. 1995. Middle Paleolithic scraper reduction: Background, clarification, and a review of the evidence to date. *Journal of Archaeological Method and Theory* 2:299–368.

Dibble, H. L., and M. C. Bernard. 1980. A comparative study of basic edge angle measurement techniques. *American Antiquity* 45:857–865.

Dibble, H. L., and P. G. Chase. 1981. A new method for describing and analyzing artifact shape. *American Antiquity* 46:178–197.

Djindjian, F. 1987. "Identification, characterization and evolution of material culture," in *Data processing and mathematics applied to archaeology*. Edited by F. Djindjian and H. Ducasse, pp. 393–421. Ravello, Italy: European University Center for the Cultural Heritage.

Dobres, M. A. 1992. "Reconsidering Venus figurines: A feminist inspired re-analysis," in *Ancient images, ancient thought: The archaeology of ideology*, vol. 23, *Proceedings, Chacmool Annual Conference*. Edited by A. Goldsmith, S. Garvie, D. Selin, and J. Smith, pp. 245–262. Calgary: University of Calgary Press.

Doran, J. E., and F. R. Hodson. 1975. *Mathematics and computers in archaeology*. Cambridge, MA: Harvard University Press.

Douglass, A. A., and O. Lindauer. 1988. Hierarchical and nonhierarchical approaches to ceramic design analysis: A response to Jernigan. *American Antiquity* 53:620–626.

Doyel, D. E., and M. D. Elson. 1985. "Ceramic analysis," in *Hohokam settlement systems and economic systems in the central New River drainage, Arizona*, vol. 2. Edited by D. E. Doyel and M. D. Elson, pp. 436–520. Phoenix: Soil Systems.

Dunnell, R. C. 1971. *Systematics in prehistory*. New York: Free Press.

———. 1978. Style and function: A fundamental dichotomy. *American Antiquity* 43:192–202.

Dunnell, R. C. 1980. Evolutionary theory and archaeology. *Journal of Anthropological Research* 38:1–25.
———. 1986. "Methodological issues in Americanist artifact classification," in *Advances in archaeological method and theory*, vol. 9. Edited by M. B. Schiffer, pp. 149–207. Orlando, FL: Academic.
———. 1993. Review of *Archaeological Typology and Practical Reality: A Dialectical Approach to Artifact Classification and Sorting* by William Y. Adams and Ernest W. Adams. *American Antiquity* 58:165–166.
———. 2001. "Foreword," in *Style and function: Conceptual issues in evolutionary archaeology*. Edited by T. D. Hurt and G. F. M. Rakita, pp. xiii–xxiv. Westport, CT: Bergin & Garvey.
Edmonds, M. 1990. Description, understanding and the *chaîne opératoire*. *Archaeological Review from Cambridge* 9:55–70.
Eglash, R. 1999. *African fractals: Modern computing and indigenous design*. New Brunswick, NJ: Rutgers University Press.
Ellis, C. J. 1989. "The explanation of Northeastern Paleoindian lithic procurement patterns," in *Eastern Paleoindian lithic resource use*. Edited by C. J. Ellis and J. C. Lothrop, pp. 139–164. Boulder, CO: Westview.
———. 1997. "Factors influencing the use of stone projectile tips," in *Projectile technology*. Edited by H. Knecht, pp. 37–74. New York: Plenum.
Ellis, C. J., and J. C. Lothrop. 1989. "Preface," in *Eastern Paleoindian lithic resource use*. Edited by C. J. Ellis and J. C. Lothrop, pp. xix–xxi. Boulder, CO: Westview.
Elston, R. G., and P. J. Brantingham. 2002. "Microlithic technology in northern Asia: A risk-minimizing strategy of the late Paleolithic and early Holocene," in *Thinking small: Global perspectives on microlithization*, vol. 12, *Archaeological Papers of the American Anthropological Association*. Edited by R. G. Elston and S. Khun, pp. 103–116. Washington, DC: American Anthropological Association.
Epsein, J. F. 1963. The burin-faceted projectile point. *American Antiquity* 29: 187–201.
Ewen, C. E. 2003. *Artifacts*, vol. 4. *Archaeologist's Toolkit*. Walnut Creek, CA: AltaMira.
Fawcett, W. B. 1998. Chronology and projectile point neck-width: An Idaho example. *North American Archaeologist* 19:59–85.
Feathers, J. K. 1989. Effects of temper on strength of ceramics: Response to Bronitsky and Hamer. *American Antiquity* 54:579–588.
Finkelstein, J. J. 1937. A suggested projectile-point classification. *American Antiquity* 2:197–203.
Fisher, R. 1954. *Statistical methods for research workers*. London: Oliver & Boyd.
Flenniken, J. J. 1981. *Replicative systems analysis: A model applied to the vein quartz artifacts from the Hoko River site*, Laboratory of Anthropology 59. Pullman: Department of Anthropology, Washington State University.
Flenniken, J. J., and A. W. Raymond. 1986. Morphological projectile point typology: Replication, experimentation, and technological analysis. *American Antiquity* 51:603–614.
Flenniken, J. J., and P. J. Wilke. 1989. Typology, technology, and chronology of Great Basin dart points. *American Anthropologist* 91:149–158.

Ford, J. A. 1952. *Measurements of some prehistoric design developments in the southeastern states, Anthropological Papers of the American Museum of Natural History* 44, Part 3.
———. 1954. On the concept of types. *American Anthropologist* 56:42–57.
Ford, J. A., and J. B. Griffin. 1999 [1938]. Report of the Conference on Southeastern Pottery Typology. Reprinted in *Measuring the Flow of Time: The Works of James A. Ford, 1935–1941*, edited by Michael J. O'Brien and R. Lee Lyman, pp. 435–449. University of Alabama Press, Tuscaloosa.
Ford, J. A., and C. H. Webb. 1956. Poverty Point: A Late Archaic site in Louisiana. *Anthropological Papers of the American Museum of Natural History* 46:1–136.
Fowke, G. 1896. *Stone art*. Washington, DC: Bureau of American Ethnology.
Freeman, L. 1992. "Mousterian facies in space: New data from Morin level 16," in *The Middle Paleolithic: Adaptation, behavior, and variability*. Edited by H. L. Dibble and P. Mellars, pp. 113–126. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.
Frison, G. C. 1973. *The Wardell buffalo trap 48SU301: Communal procurement in the upper Green River Basin*, vol. 48. *Anthropological Papers*. Ann Arbor: University of Michigan Museum of Anthropology.
———. 1976. Cultural activity associated with prehistoric mammoth butchering and processing. *Science* 194:728–730.
Frison, G. C., and G. M. Zeimens. 1980. Bone projectile points: An addition to the Folsom Cultural Complex. *American Antiquity* 45:231–237.
Fritz, J. M., and F. T. Plog. 1970. The nature of archaeological explanation. *American Anthropologist* 35:405–412.
Gallus, A. 1977. "Organic typology," in *Stone tools as cultural markers: Change, evolution and complexity. Prehistory and Material Culture Series No. 12*. Edited by R. V. S. Wright, pp. 133–145. Canberra: Australian Institute of Aboriginal Studies.
Gamble, C. 1998. Palaeolithic society and the release from proximity: A network approach to intimate relations. *World Archaeology* 29:426–449.
Gamble, L. H., P. L. Walker, and G. S. Russell. 2001. An integrative approach to mortuary analysis: Social and symbolic dimensions of Chumash burial practices. *American Antiquity* 66:185–212.
Garcia Cook, A. 1967. *Analisis tipologico de artefactos*. Mexico City: Instituto Nacional de Antropologia e História.
Geneste, J. M. 1991. Systèmes techniques de production lithique: Variations techno-économiques dans les processus de réalisation des outillages paléolithiques. *Techniques et Culture* 17/18:1–35.
Gero, J., and Mazzullo. 1984. Analysis of artifact shape using Fourier series in closed form. *Journal of Field Archaeology* 11:315–322.
Gero, J. M. 1989. "Assessing social information in material objects: How well do lithics measure up?" in *Time, energy and stone tools*. Edited by R. Torrence, pp. 92–105. Cambridge, UK: Cambridge University Press.
Gifford, J. C. 1960. The type-variety method of ceramic classification as an indicator of cultural phenomena. *American Antiquity* 25:341–347.
Gilmour, J. S. L. 1940. "Taxonomy and philosophy," in *The new systematics*. Edited by J. Huxley. Oxford: Clarendon Press.

Gladwin, H. S., E. W. Haury, E. B. Sayles, and N. Gladwin. 1937. *Excavations at Snaketown: Material culture, Medallion Papers*, No. 8. Globe, AZ: Gila Pueblo.
Gladwin, W., and H. S. Gladwin. 1930. "A method for the designation of Southwestern pottery types," in *Medallion Papers*, No. 7. Globe, AZ: Gila Pueblo.
———. 1934. "A method for the designation of cultures and their variations," in *Medallion Papers*, No. 15. Globe, AZ: Gila Pueblo.
Goodyear, A. C. 1989. "A hypothesis for the use of cryptocrystalline raw materials among Paleoindian groups of North America," in *Eastern Paleoindian lithic resource use*. Edited by C. J. Ellis and J. C. Lothrop, pp. 1–9. Boulder, CO: Westview.
Goodyear, A. C. I. 1974. *The Brand site: A techno-functional study of a Dalton site in northeast Arkansas. Research Series No. 7*. Fayatteville: Arkansas Archeological Survey.
Gordon, D. 1993. Mousterian tool selection, reduction, and discard at Ghar, Israel. *Journal of Field Archaeology* 20:205–218.
Goren-Inbar, N., and I. Saragusti. 1996. An Acheulian biface assemblage from Gesher Genot Ya'aqov, Israel: Indications of African affinities. *Journal of Field Archaeology* 23:15–30.
Gorodtsov, V. A. 1927. *Tipologicheskiy metod v arkheologii*, vol. 9. *Seriia Metodicheskaia*. Riazan, USSR: Obshchestvo Issledovateley Riazanskogo Kraya.
Gosselain, O. P. 1992. Technology and style: Potters and pottery among Bafia of Cameroon. *Man (N.S.)* 27:559–586.
Gould, R. A. 1971. The archaeologist as ethnographer: A case from the Western Desert of Australia. *World Archaeology* 3:143–177.
———. 1978. "From Tasmania to Tucson," in *New directions in ethnoarchaeology*. Edited by R. A. Gould, pp. 1–10. Albuquerque: University of New Mexico Press.
———. 1980. *Living archaeology*. Cambridge, UK: Cambridge University Press.
Gould, R. A., D. A. Koster, and A. H. L. Sontz. 1971. The lithic assemblage of the Western Desert Aborigines of Australia. *American Antiquity* 36:149–169.
Graves, M. 1981. Ethnoarchaeology of Kalinga ceramic design. Ph.D. Dissertation, University of Arizona.
———. 1984. Temporal variation among White Mountain Redware design styles. *Kiva* 50:324.
———. 1994. "Kalinga social and material culture boundaries: A case of spatial convergence," in *Kalinga ethnoarchaeology: Expanding archaeological method and theory*. Edited by W. A. Longacre and J. N. Skibo, pp. 13–49. Washington, DC: Smithsonian Institution Press.
Graves, P. 1994. Flakes and ladders: What the archaeological record cannot tell us about the origins of language. *World Archaeology* 26:158–171.
Green, M. 1982. Chipped stone raw materials and the study of interaction. Ph.D. Dissertation, Arizona State University.
Grimaldi, S., and C. Lemorini. 1993. "Retouche specialisée et/ou chaîne de ravivage? Les 'racloirs' moustériens de la Grotta Breuil (Monte Circeo, Italie)," in *Traces et fonction: Les gestes retrouvés*, vol. 50. Edited by P. Anderson, S. Beyries, M. Otte, and H. Plisson, pp. 67–78. Liege, Belgium: ERAUL.
Gunn, J. E., and E. R. Prewitt. 1975. Automatic classification: Projectile points from west Texas. *Plains Anthropologist* 20:139–149.

Guthe, C. E. 1927. A method of ceramic description. *Papers of the Michigan Academy of Science, Art and Letters* VIII:23–29.
Hardin, M. 1984. "Models of decoration," in *The many dimensions of pottery: Ceramics in archaeology and anthropology*. Edited by S. E. van der Leeuw and A. C. Pritchard, pp. 575–607. Amsterdam: Universiteit van Amserdam.
Hargrave, L. L. 1932. "Guide to forty pottery types from the Hopi country and the San Francisco Mountains, Arizona," in *Museum of Northern Arizona, Bulletin 1*.
Hargrave, L. L., and H. S. Colton. 1935. What do potsherds tell us? *Museum of Northern Arizona, Museum Notes* 7. Flagstaff: Museum of Northern Arizona.
Harris, M. 1968. *The rise of anthropological theory*. New York: Crowell.
Hart, J. P., and J. E. Terrell. Editors. 2002. *Darwin and archaeology: A handbook of key concepts*. Westport, CT: Bergin & Garvey.
Haury, E. W. 1976. *The Hohokam, desert farmers and craftsmen: Excavations at Snaketown, 1964–1965*. Tucson: University of Arizona Press.
Hawley, F. M. 1938. The family tree of Chaco Canyon masonry. *American Antiquity* 3:247–255.
Hayden, B. 1977. "Stone tool functions in the Western Desert," in *Stone tools as cultural markers: Change, evolution and complexity. Prehistory and Material Culture Series No. 12*. Edited by R. V. S. Wright, pp. 178–188. Canberra: Australian Institute of Aboriginal Studies.
———. 1984. Are emic types relevant to archaeology? *Ethnohistory* 31:79–92.
———. 1989. "From chopper to celt: The evolution of resharpening techniques," in *Time, energy and stone tools*. Edited by R. Torrence, pp. 7–16. Cambridge, UK: Cambridge University Press.
Hays-Gilpin, K. A. 1996. "Anasazi iconography: Medium and motif," in *Interpreting southwestern diversity: Underlying principles and overarching patterns, Anthropological Research Papers No. 48*. Edited by P. R. Fish and J. J. Reid, pp. 55–67. Tempe: Arizona State University.
Hegmon, M. 1992. Archaeological research on style. *Annual Review of Anthropology* 21:517–536.
Hempel, C. G. 1965. *Aspects of scientific explanation and other essays in the philosophy of science*. New York: Free Press.
Hietala, H. J., and D. Stevens. 1977. Spatial analysis: Multiple procedures in pattern recognition studies. *American Antiquity* 42:539–559.
Hill, J. 1978. Individuals and their artifacts: An experimental study in archaeology. *American Antiquity* 43:245–257.
Hill, J., and R. Evans. 1972. "A model for classification and typology," in *Models in archaeology*. Edited by D. Clarke, pp. 231–273. London: Metheun.
Hiscock, P., and V. Attenbrow. 2002. Early Australian implement variation: A reduction model. *Journal of Archaeological Science* 30:239–249.
Hodder, I. 1982. *Symbols in action*. Cambridge, UK: Cambridge University Press.
———. 1985. Postprocessual archaeology. *Advances in Archaeological Method and Theory* 8:1–26.
———. 1990. "Style as historical quality," in *Uses of style in archaeology*. Edited by M. Conkey and C. Hastorf, pp. 44–51. Cambridge: Cambridge University Press.

Hodson, F. R. 1982. "Some aspects of archaeological classification," in *Essays on archaeological typology*. Edited by R. Whallon and J. A. Brown. Evanston, IL: Center for American Archaeology Press.

Hoffman, C. M. 1989 [1985]. "Tool maintenance and point typology," in *For concordance in archaeological analysis: Bridging data structure, quantitative technique and theory*. Edited by C. Carr, pp. 566–612. Prospect Heights, IL: Waveland.

Hole, F., and R. E. Heizer. 1973. *An introduction to prehistoric archaeology*, 3rd edition. New York: Holt, Rinehart & Winston.

Holmes, W. H. 1894. "Manufacture of stone arrow-points," in *Memoirs of the International Congress of Anthropology*. Edited by C. S. Wake, pp. 120–139. Chicago: Schulte.

Honegger, M. 2001. *L'industrie lithique taillée du Néolithique moyen et final de Suisse*. Paris: Editions de Centre National de la Recherche Scientifique.

Horne, G., and G. Aiston. 1924. *Savage life in central Australia*. New York: Macmillan.

House, J. H., and R. W. Wogaman. 1978. *Windy Ridge: A prehistoric site in the inter-riverine Piedmont in South Carolina*. Columbia: Institute of Archaeology and Anthropology, University of South Carolina.

Hull, D. L. 1965. The effect of essentialism on taxonomy: Two thousand years of stasis (I). *British Journal for the Philosophy of Science* 15:314–326.

Hurt, T. D., and G. F. M. Rakita. Editors. 2001. *Style and function: Conceptual issues in evolutionary archaeology*. Westport, CT: Bergin & Garvey.

Hurt, T. D., G. F. M. Rakita, and R. D. Leonard. 2001. Models, definitions, and stylistic variation. Comment on Ortman. *American Antiquity* 66:742–743.

Inizan, M.-L., M. Reduron, H. Roche, and J. Tixier. 1995. *Technologie de la pierre taillée*, vol. 4. *Préhistoire de la Pierre Taillée*. Meudon: Centre de Recherche et d'Etudes Politiques.

Inizan, M.-L., H. Roche, and J. Tixier. 1981. *Technology of Knapped Stone*. Meudon: Centre de Recherche et d'Etudes Politiques.

Jelinek, A. 1976. "Form, function, and style in lithic analysis," in *Cultural change and continuity: Essays in honor of James Bennett Griffin*. Edited by C. E. Cleland, pp. 19–33. New York: Academic.

Jernigan, E. W. 1986. A non-hierarchical approach to ceramic decoration analysis: A southwestern example. *American Antiquity* 51:3–20.

Jones, P. R. 1981. "Experimental implement manufacture and use: A case study from Olduvai Gorge, Tanzania," in *The emergence of man*. Edited by J. Young, E. Jope, and K. Oakley, pp. 189–195. London: Royal Society and the British Academy.

Jones, R. 1995. Tasmanian archaeology: Establishing the sequences. *Annual Review of Anthropology* 24:423–446.

Julien, C. K., and M. Julien. 1994. "Prehistoric technology: A cognitive science?" in *The ancient mind, elements of cognitive archaeology*. Edited by C. Renfrew and E. Zubrow, pp. 152–163. Cambridge, UK: Cambridge University Press.

Kay, M. 1975. Social distance among central Missouri Hopewell settlements. *American Antiquity* 40:64–71.

Kay, M. 1980. *The central Missouri Hopewell subsistence-settlement system*. *Missouri Archaeological Society Research Series No. 15*. Columbia: Missouri Archaeological Society.

Keesing, R. 1974. Theories of Culture. *Annual Review of Anthropology* 3:73–97.

———. 1975. *Kin groups and social structure*. New York: Holt, Rinehart & Winston.

Kehoe, T. F. 1966. The small side-notched point system of the northern plains. *American Antiquity* 31:827–841.

Kempton, W. 1981. *The folk classification of ceramics*. New York: Academic.

Kidder, A. V., and A. O. Shepard. 1936. *The pottery of Pecos, vol. 2: The glaze paint, culinary, and other wares*. *Papers of the Phillips Academy, Southwestern Expedition*. New Haven, CT: Yale University Press.

Kintigh, K. W. 1987. The archaeologist's analytical toolkit. *Archaeological Computing Newsletter* 10:4–6.

Klejn, L. S. 1982. *Archaeological typology*. *BAR International Series No. 153*. Oxford: British Archaeological Reports.

Klemptner, L. J., and P. F. Johnson. 1986. "Technology and the primitive potter; Mississippian pottery development seen through the eyes of a ceramic engineer," in *Ceramics and civilization*, vol. 2. Edited by W. D. Kingery and E. Lense, pp. 251–271.Westerville, OH: American Ceramic Society.

Kneberg, M. 1956. Some important projectile point types found in the Tennessee area. *Tennessee Archaeologist* 12:17–28.

Knecht, H. 1997. "Projectile points of bone, antler, and stone: Experimental exploration of manufacture and use," in *Projectile technology*. Edited by H. Knecht, pp. 191–212. New York: Plenum.

Kohler, T. A., and M. H. Matthews. 1988. Long-term Anasazi land use and forest reduction: A case study from southwest Colorado. *American Antiquity* 53:537–564.

Kooyman, B. P. 2000. *Understanding stone tools and archaeological sites*. Calgary: University of Calgary Press.

Krajnov, D. A. 1972. *Drevnejsaja istorja Volgo-Okskogo mezdurec'ja: Fat'janovskaja kul'tura: II tysjaceletie do n.e.*Moscow: Akademija Nauk SSSR. Institut archeologii.

Krause, R. 1984. "Modelling the making of pots: An ethnoarchaeological approach," in *The many dimensions of pottery: Ceramics in archaeology and anthropology*. Edited by S. E. van der Leeuw and A. C. Pritchard. Amsterdam: Universiteit van Amsterdam.

———. 1985. *The clay sleeps: An ethnoarchaeological study of three African potters*. Tuscaloosa: University of Alabama Press.

———. 1990. Ceramic practice and semantic space: An ethnoarchaeological inquiry into the logic of Bantu potting. *Antiquity* 64:711–726.

Krieger, A. D. 1944. The typological concept. *American Antiquity* 9:271–288.

Kroeber, A. L., and C. Kluckhohn. 1952. *Culture: A critical review of concepts and definitions*, vol. 47, no. 1, *Papers of the Peabody Museum of American Archeology and Ethnology*. Cambridge, MA: *Harvard University*.

Kuhl, F. P., and C. R. Giardina. 1982. Elliptic Fourier features of a closed contour. *Computer Graphics and Image Processing* 18:236–258.

Kuhn, S. L. 1992. Blank form and reduction as determinants of Mousterian scraper morphology. *American Antiquity* 48:185–214.

Kwon, H. S. 2005. *A regional analysis of the Kaya polities in Korea: Chronology, economy, and sociopolitical interactions in systemic perspective*. Seoul: Sowha Publishing Co.

Lagrange, M.-S. 1992. "Symbolic data and numerical processing: A case study in art history by means of automated learning techniques," in *Representations in archaeology*. Edited by J.-C. Gardin and C. S. Peebles, pp. 330–356. Bloomington: Indiana University Press.

Leaf, M. 2004. Cultural systems and organizational processes: Observations on the conference papers. *Cybernetics and Systems: An International Journal* 35:289–313.

Lechtman, H., and R. S. Merrill. Editors. 1977. *Material culture, styles, organization, and dynamics of technology. 1975 Proceedings of the American Ethnological Society*. St. Paul, MN: West.

Lemonnier, P. 1976. La description des chaînes opératoires: Contribution à l'analyse des systèmes techniques. *Techniques Culturelle* 1:100–151.

———. 1983. L'étude des systèmes techniques, une urgence en technologie culturelle. *Techniques Culturelle* 1:11–26.

———. 1986. The study of material culture today: Toward an anthropology of technical systems. *Journal of Anthropological Archaeology* 5:147–186.

———. 1992. *Elements for an anthropology of technology*, vol. 88. *Anthropological Papers*. Ann Arbor: University of Michigan Museum of Anthropology.

———. 1993. "Introduction," in *Technological choices: Transformations in material cultures since the Neolithic*. Edited by P. Lemonnier, pp. 1–35. London: Routledge.

Lerman, M. I. C. 1970. "H-classificabilité," in *Archéologie et calculateurs*. Edited by J. C. Gardin, pp. 319–325. Paris: Editions du Centre National de la Recherche Scientifique.

Leroi-Gourhan, A. 1943. *Evolution et techniques. Tome I: L'Homme et la matière*. Paris: Albin Michel.

———. 1964. *Le geste et la parole, 1: Techniques et langage, 2: La mémoire et les rythmes*. Paris: Albin Michel.

Lestrel, P. E. Editor. 1997. *Fourier descriptors and their applications in biology*. Cambridge, UK: Cambridge University Press.

Levin, M. E. 1973. On explanation in archaeology: A rebuttal to Fritz and Plog. *American Antiquity* 38.

Lewis, R. B. 1986. "The analysis of contingency tables in archaeology," in *Advances in Archaeological Method and Theory*, vol. 9. Edited by M. B. Schiffer, pp. 277–310. Orlando, FL: Academic.

Limp, F. W., and C. Carr. 1989 [1985]. "The analysis of decision making: Alternative applications in archaeology," in *For concordance in archaeological analysis*. Edited by C. Carr, pp. 128–172. Prospect Heights, IL: Waveland.

Lipo, C., and M. Madsen. 2001. "Neutrality, 'style,' and drift: Building methods for studying cultural transmission in the archaeological record," in *Style and function: Conceptual issues in evolutionary archaeology*. Edited by T. D. Hurt and G. F. M. Rakita, pp. 91–118. Westport, CT: Bergin & Garvey.

Luchterhand, K. 1970. *Early archaic projectile points and hunting patterns in the Lower Illinois Valley. Illinois Archaeological Survey, Monograph* 2. Springfield: Illinois Archaeological Survey.

Lyman, R. L., and M. J. O'Brien. 1998. The goals of evolutionary archaeology: History and explanation. *Current Anthropology* 39:615–652.

———. 2004. A history of normative theory in Americanist archaeology. *Journal of Archaeological Method and Theory* 11:369–396.

Magne, M. P. R. 1985. *Lithics and livelihood: Stone tool technologies of central and southern interior British Columbia. Mercury Series No. 133*. Archaeological Survey of Canada. Ottawa: National Museum of Man.

Main, P. L. 1978. "The storage, retrieval and classification of artefact shapes," in *Computers in archaeology*. Edited by S. Laflin, pp. 39–48. Birmingham, UK: University of Birmingham.

Malmer, M. P. 1962. *Jungneolithische studien*, vol. 2. *Acta Archaeologia Lundensia*. Bonn: Habelt-Gleerup.

Marshak, B. I. 1970. *Kod dlia opisaniia keramiki Pendzhikenta V–VI vv. Statistiko-kombinatornye metody v arkheologii*. Moscow: Nauka.

Marshall, L. 1976. *The !Kung of Nyae Nyae*. Cambridge, MA: Harvard University Press.

Martin, P. S., J. B. Rinaldo, E. Bluhm, H. C. Cutler, and R. J. Grange. 1952. *Mogollon cultural continuity and change: The stratigraphic analysis of Tularosa and Cordova Caves*, vol. 40. *Fieldiana: Anthropology*. Chicago: Chicago Natural History Museum.

McGuire, J. D. 1899. *Pipes and smoking customs of the American aborigines based on material in the U. S. National Museum*. Annual Report (1897), Part I, pp. 351–647. Washington, DC: United States National Museum.

McKern, W. C. 1939. The Midwestern Taxonomic Method as an aid to archaeological culture study. *American Antiquity* 4:301–313.

McPherron, S. P. 2003. "Technological and typological variability in the bifaces from Tabun Cave, Israel," in *Multiple approaches to the study of bifacial technologies*. Edited by M. Soressi and H. L. Dibble. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Mead, H. M. 1990. "Tribal art as symbols of identity," in *Art and identity in Oceania*. Edited by A. Hanson and L. Hanson, pp. 269–281. Honolulu: University of Hawaii Press.

Mellars, P. 1991. Cognitive changes and the emergence of modern humans in Europe. *Cambridge Archaeological Journal* 1:63–76.

———. 1992. "Technological change in the Mousterian of southwest France," in *The Middle Paleolithic: Adaptation, behavior, and variability*, Monograph 78. Edited by H. L. Dibble and P. Mellars, pp. 29–43. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Meltzer, D. J. 1981. A study of style and function in a class of tools. *Journal of Field Archaeology* 8:313–326.

Milke, W. 1949. The quantitative distribution of cultural similarities and their cartographic representation. *American Anthropologist* 51:237–252.

Kuhn, S. L. 1992. Blank form and reduction as determinants of Mousterian scraper morphology. *American Antiquity* 48:185–214.

Kwon, H. S. 2005. *A regional analysis of the Kaya polities in Korea: Chronology, economy, and sociopolitical interactions in systemic perspective*. Seoul: Sowha Publishing Co.

Lagrange, M.-S. 1992. "Symbolic data and numerical processing: A case study in art history by means of automated learning techniques," in *Representations in archaeology*. Edited by J.-C. Gardin and C. S. Peebles, pp. 330–356. Bloomington: Indiana University Press.

Leaf, M. 2004. Cultural systems and organizational processes: Observations on the conference papers. *Cybernetics and Systems: An International Journal* 35:289–313.

Lechtman, H., and R. S. Merrill. Editors. 1977. *Material culture, styles, organization, and dynamics of technology. 1975 Proceedings of the American Ethnological Society*. St. Paul, MN: West.

Lemonnier, P. 1976. La description des chaînes opératoires: Contribution à l'analyse des systèmes techniques. *Techniques Culturelle* 1:100–151.

———. 1983. L'étude des systèmes techniques, une urgence en technologie culturelle. *Techniques Culturelle* 1:11–26.

———. 1986. The study of material culture today: Toward an anthropology of technical systems. *Journal of Anthropological Archaeology* 5:147–186.

———. 1992. *Elements for an anthropology of technology*, vol. 88. *Anthropological Papers*. Ann Arbor: University of Michigan Museum of Anthropology.

———. 1993. "Introduction," in *Technological choices: Transformations in material cultures since the Neolithic*. Edited by P. Lemonnier, pp. 1–35. London: Routledge.

Lerman, M. I. C. 1970. "H-classificabilité," in *Archéologie et calculateurs*. Edited by J. C. Gardin, pp. 319–325. Paris: Editions du Centre National de la Recherche Scientifique.

Leroi-Gourhan, A. 1943. *Evolution et techniques. Tome I: L'Homme et la matière*. Paris: Albin Michel.

———. 1964. *Le geste et la parole, 1: Techniques et langage, 2: La mémoire et les rythmes*. Paris: Albin Michel.

Lestrel, P. E. Editor. 1997. *Fourier descriptors and their applications in biology*. Cambridge, UK: Cambridge University Press.

Levin, M. E. 1973. On explanation in archaeology: A rebuttal to Fritz and Plog. *American Antiquity* 38.

Lewis, R. B. 1986. "The analysis of contingency tables in archaeology," in *Advances in Archaeological Method and Theory*, vol. 9. Edited by M. B. Schiffer, pp. 277–310. Orlando, FL: Academic.

Limp, F. W., and C. Carr. 1989 [1985]. "The analysis of decision making: Alternative applications in archaeology," in *For concordance in archaeological analysis*. Edited by C. Carr, pp. 128–172. Prospect Heights, IL: Waveland.

Lipo, C., and M. Madsen. 2001. "Neutrality, 'style,' and drift: Building methods for studying cultural transmission in the archaeological record," in *Style and function: Conceptual issues in evolutionary archaeology*. Edited by T. D. Hurt and G. F. M. Rakita, pp. 91–118. Westport, CT: Bergin & Garvey.

Luchterhand, K. 1970. *Early archaic projectile points and hunting patterns in the Lower Illinois Valley. Illinois Archaeological Survey, Monograph* 2. Springfield: Illinois Archaeological Survey.

Lyman, R. L., and M. J. O'Brien. 1998. The goals of evolutionary archaeology: History and explanation. *Current Anthropology* 39:615–652.

———. 2004. A history of normative theory in Americanist archaeology. *Journal of Archaeological Method and Theory* 11:369–396.

Magne, M. P. R. 1985. *Lithics and livelihood: Stone tool technologies of central and southern interior British Columbia. Mercury Series No. 133*. Archaeological Survey of Canada. Ottawa: National Museum of Man.

Main, P. L. 1978. "The storage, retrieval and classification of artefact shapes," in *Computers in archaeology*. Edited by S. Laflin, pp. 39–48. Birmingham, UK: University of Birmingham.

Malmer, M. P. 1962. *Jungneolithische studien*, vol. 2. *Acta Archaeologia Lundensia*. Bonn: Habelt-Gleerup.

Marshak, B. I. 1970. *Kod dlia opisaniia keramiki Pendzhikenta V–VI vv. Statistiko-kombinatornye metody v arkheologii*. Moscow: Nauka.

Marshall, L. 1976. *The !Kung of Nyae Nyae*. Cambridge, MA: Harvard University Press.

Martin, P. S., J. B. Rinaldo, E. Bluhm, H. C. Cutler, and R. J. Grange. 1952. *Mogollon cultural continuity and change: The stratigraphic analysis of Tularosa and Cordova Caves*, vol. 40. *Fieldiana: Anthropology*. Chicago: Chicago Natural History Museum.

McGuire, J. D. 1899. *Pipes and smoking customs of the American aborigines based on material in the U. S. National Museum*. Annual Report (1897), Part I, pp. 351–647. Washington, DC: United States National Museum.

McKern, W. C. 1939. The Midwestern Taxonomic Method as an aid to archaeological culture study. *American Antiquity* 4:301–313.

McPherron, S. P. 2003. "Technological and typological variability in the bifaces from Tabun Cave, Israel," in *Multiple approaches to the study of bifacial technologies*. Edited by M. Soressi and H. L. Dibble. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Mead, H. M. 1990. "Tribal art as symbols of identity," in *Art and identity in Oceania*. Edited by A. Hanson and L. Hanson, pp. 269–281. Honolulu: University of Hawaii Press.

Mellars, P. 1991. Cognitive changes and the emergence of modern humans in Europe. *Cambridge Archaeological Journal* 1:63–76.

———. 1992. "Technological change in the Mousterian of southwest France," in *The Middle Paleolithic: Adaptation, behavior, and variability*, Monograph 78. Edited by H. L. Dibble and P. Mellars, pp. 29–43. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Meltzer, D. J. 1981. A study of style and function in a class of tools. *Journal of Field Archaeology* 8:313–326.

Milke, W. 1949. The quantitative distribution of cultural similarities and their cartographic representation. *American Anthropologist* 51:237–252.

Miller, D. 1985. *Artefacts as categories*. Cambridge, UK: Cambridge University Press.

Montet-White, A. 1973. *Le Malpas rockshelter: A study of Late Paleolithic technology in its environmental setting*. Lawrence: University Press of Kansas.

———. 1974. Significance of variability in Archaic point assemblages. *Plains Anthropologist* 19:14–24.

Montet-White, A., and A. E. Johnson. 1976. Kadar: A late Gravettian site in northern Bosnia, Yugoslavia. *Journal of Field Archaeology* 3:407–424.

Morley, S. E. 2002. Stylistic variation and group self-identity: Evidence from the Rio Grande pueblos. Ph.D. Dissertation, University of California Los Angeles.

Morris, E. H. 1927. The beginnings of pottery making in the San Juan area: Unfired proto-types and the wares of the earliest ceramic period. *Anthropological Papers of the American Museum of Natural History* 28:125–198.

Morse, D. F. 1971. The Hawkins cache: A significant Dalton find in northeast Arkansas. *Arkansas Archaeologist* 12:9–20.

Mueller, J. Editor. 1975. *Sampling in archaeology*. Tucson: University of Arizona Press.

Neiman, F. D. 1995. Stylistic variation in evolutionary perspective: Inferences from decorative diversity and interassemblage distance in Illinois Woodland Ceramic assemblages. *American Antiquity* 60:7–36.

Nelson, M. C. 1997. "Projectile points: Form, function, and design," in *Projectile technology*. Edited by H. Knecht, pp. 371–384. New York: Plenum.

Neustupný, E. 1993. *Archaeological method*. Cambridge, UK: Cambridge University Press.

Newell, H. P., and A. D. Krieger. 1949. *The George C. Davis site, Cherokee County, Texas. Memoirs No. 5*. Menasha, WI: Society for American Archaeology.

Nicholson, P., and H. Patterson. 1985. Pottery making in Upper Egypt: An ethnoarchaeological study. *World Archaeology* 17:222–239.

Noah, A. 2005. Household economies: The role of animals in a historic period chiefdom on the California coast. Ph.D. Dissertation, University of California, Los Angeles.

O'Brien, M. J. 2005. Evolutionism and North America's archaeological record. *World Archaeology* 37:26–45.

O'Brien, M. J., and T. D. Holland. 1992. The role of adaptation in archaeological explanation. *American Antiquity* 57:3–59.

O'Brien, M. J., T. D. Holland, R. J. Hoard, and G. L. Fox. 1994. Evolutionary implications of design and performance characteristics of prehistoric pottery. *Journal of Archaeological Method and Theory* 1:259–304.

O'Brien, M. J., and R. L. Lyman. 2000. *Applying evolutionary archaeology: A systematic approach*. New York: Kluwer Academic/Plenum.

———. 2003. *Cladistics and archaeology*. Salt Lake City: University of Utah Press.

Odell, G. H. 1989. *Experiments in lithic reduction. BAR International Series No. 528*. Oxford: British Archaeological Reports.

———. 2001. Stone tool research at the end of the millennium: Classification, function, and behavior. *Journal of Archaeological Research* 9:45–100.

Odell, G. H., and F. Cowan. 1986. Experiments with spears and arrows on animal targets. *Journal of Field Archaeology* 13:195–212.

Odell, G. H., B. D. Hayden, J. K. Johnson, M. Kay, T. A. Morrow, S. E. Nash, M. S. Nassaney, J. W. Rick, M. F. Rondeau, S. A. Rosen, M. J. Shott, and P. T. Thacker. 1996. "Some comments on a continuing debate," in *Stone tools: Theoretical insights into human prehistory*. Edited by G. H. Odell, pp. 377–392. New York: Plenum.

Odell, G. H., and F. Odell-Vereecken. 1980. Verifying the reliability of lithic use-wear assessments by "blind tests": The low-power approach. *Journal of Field Archaeology* 7:87–120.

Olson, A. P. 1962. A history of the phase concept in the Southwest. *American Antiquity* 27:457–472.

Olson, R. L. 1930. *Chumash prehistory, Publications in American Archaeology and Ethnology*. Berkeley: University of California, Berkeley.

Pavesic, M. G. 1985. "Cache blades and turkey tails: Piecing together the western Idaho archaic burial complex," in *Stone tool analysis: Essays in honor of Don E. Crabtree*. Edited by M. G. Plew, J. C. Woods, and M. G. Pavesic, pp. 55–89. Albuquerque: University of New Mexico Press.

Pelegrin, J. 2005. "Remarks about archaeological techniques and methods of knapping: Elements of a cognitive approach to flint knapping," in *Stone knapping: The necessary conditions for a uniquely hominin behaviour*. Edited by V. Roux and B. Bril, pp. 23–33. Exeter, UK: Short Run Press.

Pelegrin, J., C. Karlin, and P. Bodu. 1989. "Chaînes opératoires: Un outil pour le préhistorien," in *Technologie préhistorique: Notes et Monographies Techniques*. Edited by J. Tixier, pp. 55–62. Paris: Editions du Centre National de la Recherche Scientifique.

Perlès, C. 1992. "In search of lithic strategies: A cognitive approach to prehistoric chipped stone assemblages," in *Representations in archaeology*. Edited by J.-C. Gardin and C. S. Peebles, pp. 223–247. Bloomington: Indiana University Press.

Phillips, P. 1958. Application of the Wheat-Gifford-Wasley taxonomy to eastern ceramics. *American Antiquity* 24:117–130.

Phillips, P., J. A. Ford, and J. B. Griffin. 1951. *Archaeological survey in the lower Mississippi alluvial valley 1940–1947*, vol. 25, *Papers of the Peabody Museum of American Archeology and Ethnology*. Cambridge, MA: Harvard University.

Pigeot, N. 1991. Réflexions sur l'histoire technique de l'homme: de l'évolution cognitive à l'évolution culturelle. *Paléo* 3:167–200.

Pike, K. 1967. *Language in relation to a unified theory of the structures of human behavior*, 2nd edition. The Hague: Mouton.

Plog, S. 1983. Analysis of style in artifacts. *Annual Review of Anthropology* 12: 125–142.

Popper, K. R. 1950. *The open society and its enemies*. Princeton, NJ: Princeton University Press.

Ramenofsky, A. F., and A. Stefen. 1998. "Units as tools of measurements," in *Unit issues in archaeology: Measuring time, space, and material*. Edited by A. F. Ramenofsky and A. Stefen, pp. 3–17. Salt Lake City: University of Utah Press.

Rau, C. 1876. The archaeological collection of the United States National Museum, in charge of the Smithsonian Museum. *Smithsonian Contributions of Knowledge, vol.* 22, no. 287. Washington, DC: Smithsonian Institution.

Read, D. 1974a. On (J, M, m)-extensions of Boolean algebras. *Pacific Journal of Mathematics* 53:146–172.

———. 1974b. Some comments on typologies in archaeology and an outline of a methodology. *American Antiquity* 39:216–242.

———. 1975. "Regional sampling," in *Sampling in archaeology*. Edited by J. Mueller, pp. 45–60. Tucson: University of Arizona Press.

———. 1982. "Toward a theory of archaeological classification," in *Essays on archaeological typology*. Edited by R. Whallon and J. A. Brown. Evanston, IL: Center for American Archaeology Press.

———. 1986. Sampling procedures for regional surveys. *Journal of Field Archaeology* 13:103–122.

———. 1987. "Archaeological theory and statistical methods: Discordance, resolution and new directions," in *Quantitative research in archaeology: Progress and prospects*. Edited by M. Aldenderfer. Newbury Park, CA: Sage.

———. 1989a. Statistical methods and reasoning in archaeological research: A review of praxis and promise. *Journal of Quantitative Anthropology* 1:5–78.

———. 1989b [1985]. "The substance of archaeological analysis and the mold of statistical method: Enlightenment out of discordance?" in *For concordance in archaeological analysis: Bridging data structure, quantitative technique and theory*. Edited by C. Carr, pp. 45–86. Prospect Heights, IL: Waveland.

———. 2005a. "Quantitative analysis, anthropology," in *Encyclopedia of Social Measurements*, vol. 3. Edited by K. Kempf-Leonard. New York: Elsevier Academic.

———. 2005b. Some observations on resilience and robustness in human systems. *Cybernetics and Systems: An International Journal* 36:773–802.

———. 2006. Tasmanian knowledge and skill: maladaptive imitation or adequate technology? *American Antiquity* 71:164–184.

Read, D., and S. LeBlanc. 2003. Population growth, carrying capacity, and conflict. *Current Anthropology* 44:59–85.

Read, D., and P. E. Lestrel. 1986. Comment on uses of homologous point measures in systematics. *Systematic Zoology* 35:141–253.

Read, D., and G. Russell. 1996. A method for taxonomic typology construction and an example: Utilized flakes. *American Antiquity* 61:663–684.

Redman, C. L. 1978. "Multivariate artifact analysis: A basis for multidimensional interpretations," in *Social archaeology: Beyond subsistence and dating*. Edited by C. L. Redman, M. J. Berman, E. V. Curtin, W. T. Langhorne, N. M. Versaggi, and J. C. Wanser, pp. 159–192. New York: Academic.

Regnier, M. S. 1970. "Non fécondité du modèle statistique général de la classification automatique," in *Archéologie et calculateurs*. Edited by J. C. Gardin, pp. 301–306. Paris: Editions du Central National de la Recherche Scientifique.

Rice, P. M. 1977. Whiteware pottery production in the Valley of Guatemala: Specialization and resource utilization. *Journal of Field Archaeology* 4:221–233.

Rice, P. M. 1982. "Pottery production, pottery classification, and the role of physicochemical analyses," in *Archaeological ceramics*. Edited by J. Olin and A. Franklin, pp. 47–56. Washington, DC: Smithsonian Institution Press.

Rick, J. 1980. *Prehistoric hunters of the high Andes*. New York: Academic.

Ritchie, W. A., and R. S. MacNeish. 1949. The pre-Iroquoian pottery of New York State. *American Antiquity* 15:97–124.

Roberts, F. H. H., Jr. 1929. *Shabik'eschee village: A Late Basket Maker site in the Chaco Canyon, New Mexico. Bureau of American Ethnology Bulletin 92*. Washington, DC: Smithsonian Institution.

Roe, D. A. 1964. The British Lower and Middle Paleolithic: Some problems, method of study and preliminary results. *Proceedings of the Prehistoric Society* 30:245–267.

———. 1968. British Lower and Middle Palaeolithic handaxe groups. *Proceedings of the Prehistoric Society* 34:1–82.

Rolland, N. 1981. The interpretation of Middle Paleolithic variability. *Man (N.S.)* 16:15–42.

Rolland, N., and H. L. Dibble. 1990. A new synthesis of Middle Paleolithic variability. *American Antiquity* 55:480–499.

Rondeau, M. F. 1996. "When is an Elko?" in *Stone Tools: Theoretical Insights into Human Prehistory*. Edited by G. H. Odell, pp. 229–243. New York: Plenum.

Rosenberg, M. 1994. Pattern, process, and hierarchy in the evolution of culture. *Journal of Anthropological Archaeology* 13.

———. 1998. Comments. *Current Anthropology* 39:639–640.

Rouse, I. 1939. *Prehistory in Haiti: A Study in Method. Yale University Publications in Anthropology, Number 21*. New Haven, CT: Yale University Press.

———. 1941. *Culture of the Ft. Liberté region, Haiti. Yale University Publications in Anthropology, No. 24*. New Haven, CT: Yale University Press.

———. 1952. "Porto Rican prehistory," in *The New York Academy of Sciences, Scientific Survey of Porto Rico and the Virgin Islands*, vol. 18, Nos. 3–4, pp. 307–578. New York: New York Academy of Sciences.

———. 1960. The classification of artifacts in archaeology. *American Antiquity* 25:313–323.

Rye, O. S. 1981. *Pottery technology: Principles and reconstruction. Manuals on Archaeology, 4*. Washington, DC: Taraxacum.

Sackett, J. 1966. Quantitative analysis of Upper Paleolithic stone tools. *American Anthropologist* 68:356–394.

———. 1977. The meaning of style in archaeology: A general model. *American Antiquity* 42:369–380.

———. 1982. Approaches to style in lithic archaeology. *Journal of Anthropological Archaeology* 1:59–112.

———. 1985. Style and ethnicity in the Kalahari: A reply to Wiessner. *American Antiquity* 50:154–159.

———. 1986. Style, function, and assemblage variability: A reply to Binford. *American Antiquity* 51:628–634.

———. 1988. "The Mousterian and its aftermath: A view from the Upper Paleolithic," in *Upper Pleistocene prehistory of western Eurasia*. Edited by H. L. Dibble and

A. Montet-White, pp. 413–426. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

SAS (Statistical Analysis Systems). 1989. *SAS/STAT® User's Guide. Version 6*, 4th edition. Vol. 1. Cary, NC: SAS Institute.

Schiffer, M. B. 1988. "The effects of surface treatment on permeability and evaporative cooling effectiveness of pottery," in *Proceedings of the 26th International Archaeometry Symposium*. Edited by R. M. Farquhar, R. G. V. Hancock, and L. A. Pavlish, pp. 23–29. Toronto: Archaeometry Laboratory, Department of Physics, University of Toronto.

———. 1990a. "Technological change in water-storage and cooking pots: Some predictions from experiments," in *The changing roles of ceramics in society: 26,000 B. P. to the present*. Edited by W. D. Kingery, pp. 119–136. Westerville, OH: American Ceramic Society.

———. 1990b. The influence of surface treatment on heating effectiveness of ceramic vessels. *Journal of Archaeological Science* 28:595–622.

———. 1990c. The influence of surface treatment on heating effectiveness of ceramic vessels. *Journal of Archaeological Science* 17:373–381.

———. 1996. Some relationships between behavioral and evolutionary archaeologies. *American Antiquity* 61:643–662.

———. 2002 [1976]. *Behavioral archeology*. Clinton Corners, NY: Percheron Press/ Eliot Werner Publications.

Schiffer, M. B., and J. N. Skibo. 1987. Theory and experiment in the study of technological change. *Current Anthropology* 28:595–622.

Schiffer, M. B., J. N. Skibo, T. C. Boelke, M. A. Neupert, and A. Aronson. 1994. New perspectives on experimental archaeology: Surface treatments and thermal response of the clay and thermal response of the clay cooking pot. *American Antiquity* 59:197–217.

Schlanger, N. 1994. "Mindful technology: Unleashing the *chaîne opératoire* for an archaeology of the mind," in *The ancient mind: Elements of cognitive archaeology*. Edited by C. Renfrew and E. Zubrow, pp. 143–151. Cambridge, UK: Cambridge University Press.

Schroeder, A. H. 1952. The bearing of ceramics on developments in the Hohokam classic period. *Southwestern Journal of Anthropology* 8:320–335.

Scriven, M. 1958. "Definitions, explanations, and theories," in *Minnesota studies in the Philosophy of Science*, vol. 2. Edited by H. Feigl, M. Scriven, and G. Maxwell, pp. 99–195. Minneapolis: University of Minnesota Press.

Sellet, R. 1993. Chaîne opératoire: The concept and its applications. *Lithic Technology* 18:106–112.

Shafer, H. J. 1985. "A technological study of two Maya lithic workshops at Colha, Belize," in *Stone tool analysis: Essays in honor of Don H. Crabtree*. Edited by M. G. Plew, J. C. Woods, and M. G. Pavesic, pp. 277–315. Albuquerque: University of New Mexico Press.

Shanks, M., and C. Tilley. 1987a. *Reconstructing archaeology: Theory and practice*. Cambridge, UK: Cambridge University Press.

———. 1987b. *Social theory and archaeology*. Albuquerque: University of New Mexico Press.

Sheets, P. D. 1975. Behavioral Analysis and the Structure of a Prehistoric Industry. *Current Anthropology* 16:369–391.

Shenkel, J. R. 1973. Review of *Systematics in Prehistory* by Robert Dunnell. *American Antiquity* 75:505–506.

Shennan, S. J. 2002. *Genes, memes and human history: Darwinian archeology and cultural evolution*. London: Thames & Hudson.

Shennan, S. J., and J. R. Wilkinson. 2001. Ceramic style change and neutral evolution: A case study from Neolithic Europe. *American Antiquity* 66:577–593.

Shepard, A. O. 1956. *Ceramics for the archaeologist. Carnegie Institute of Washington, Publication, No. 609*. Washington, DC.

Shott, M. J. 1996. "Innovation and selection in prehistory: A case study in the American bottom," in *Stone tools: Theoretical insights into human prehistory*. Edited by G. H. Odell, pp. 279–309. New York: Plenum.

———. 2003. "Time as sequence, time as ideal: Whole-object measurement of biface size and form in midwestern North America," in *Multiple approaches to the study of biface technology*. Edited by M. Soressi and H. L. Dibble, pp. 251–271. Philadelphia: University of Pennsylvania Museum of Archaeology and Anthropology.

Sinclair, A. 1995. The technique as a symbol in Late Glacial Europe. *World Archaeology* 27:50–62.

Smith, M. W. 1954. Attributes and the discovery of projectile point types: With data from the Columbia-Fraser region. *American Antiquity* 20:15–26.

Smith, W. 1962. Schools, pots, and potters. *American Anthropologist* 4:1165–1178.

Smitsman, A. W., R. F. A. Cox, and R. M. Bongers. 2005. "Action dynamics in tool use," in *Stone knapping: The necessary conditions for a uniquely hominin behaviour*. Edited by V. Roux and B. Bril, pp. 129–144. Exeter, UK: Short Run Press.

Sokal, R. R., and P. H. A. Sneath. 1963. *Principles of numerical taxonomy*. San Francisco: Freeman.

South, S. 2002 [1977]. *Method and theory in historical archeology*. Clinton Corners, NY: Percheron Press/Eliot Werner Publications.

Spaulding, A. C. 1953. Statistical techniques for the discovery of artifact types. *American Antiquity* 18:305–313.

———. 1960. "Statistical description and comparison of artifact assemblages," in *The application of quantitative methods in archaeology, Viking Fund Publications in Anthropology, No. 28*. Edited by R. E. Heizer and S. F. Cook. Chicago: Quadrangle.

———. 1974. Review of *Systematics in Prehistory* by Robert Dunnell. *American Antiquity* 39:513–516.

———. 1976. "Multifactor analysis of association: An application to Owasco ceramics," in *Cultural change and continuity: Essays in honor of James Bennett Griffin*. Edited by C. E. Cleland, pp. 59–68. New York: Academic.

———. 1977. On growth and form in archaeology: Multivariate analysis. *Journal of Anthropological Research* 33:1–15.

———. 1982. "Structure in archaeological data: Nominal variables," in *Essays on archaeological typology*. Edited by R. Whallon and J. A. Brown, pp. 1–20. Evanston, IL: Center for American Archaeology Press.

Spencer, C. S. 1997. Evolutionary approaches in archaeology. *Journal of Archaeological Research* 5:209–264.

Spier, L. 1928. *Havusupai ethnography, Anthropological Papers.* New York: American Museum of Natural History.

SPSS (Statistical Package for the Social Sciences). 2003. *SPSS Base 12.0 for Windows, User's Guide.* Chicago: SPSS, Inc.

Stark, B. L. 1995. "Analysis of standardization and specialization," in *Ceramic production in the American Southwest.* Edited by B. J. Mills and P. L. Crown, pp. 231–267. Tucson: University of Arizona Press.

Steward, J. H. 1941. Review of *Prehistoric Culture Units and Their Relationship in Northern Arizona* by H. S. Colton. *American Antiquity* 6:366–367.

Strong, W. D. 1935. An introduction to Nebraska archaeology. *Smithsonian Miscellaneous Collections,* vol. 93, no. 10. Washington, DC: Smithsonian Institution.

Suhm, D. A., A. D. Krieger, and E. B. Jelks. 1954. *An introductory handbook of Texas archaeology. Bulletin of the Texas Archeological Society,* vol. 25. Austin: Texas Archeological Society.

Taylor, W. W. 1948. A study of archeology. *American Anthropologist* 50:1–256.

Thomas, D. H. 1970. Archaeology's operational imperative: Great Basin projectile points as a test case. *University of California Archaeological Survey Annual Report* 12:27–60.

———. 1972. The use and abuse of numerical taxonomy in archaeology. *Archaeology and Physical Anthropology in Oceania* 7:31–49.

———. 1981. How to classify the projectile points from Monitor Valley, Nevada. *Journal of California and Great Basin Anthropology* 3:7–43.

———. 1986. Points on points: A reply to Flenniken and Raymond. *American Antiquity* 51:619–627.

Tilley, C. 1984. "Ideology and the legitimation of power in the Middle Neolithic of southern Sweden," in *Ideology, power and prehistory.* Edited by D. Miller and C. Tilley, pp. 111–146. Cambridge, UK: Cambridge University Press.

Timmins, P. H., and J. P. Staeck. 1999. "A flexible model for the study of precontact social and political complexity in the Midwest and Great Lakes regions," in *Taming the taxonomy,* pp. 151–174. Toronto: Eastendbooks.

Tindale, N. B. 1985. "Australian aboriginal techniques of pressure-flaking stone implements: Some personal observations," in *Stone tool analysis: Essays in honor of Don E. Crabtree.* Edited by M. G. Plew, J. C. Woods, and M. G. Pavesic. Albuquerque: University of New Mexico Press.

Titmus, G. L., and J. C. Woods. 1986. An experimental study of projectile point fracture patterns. *Journal of California and Great Basin Anthropology* 8:37–49.

Tomášková, S. 2005. What is a burin? Typology, technology, and interregional comparison. *Journal of Archaeological Method and Theory* 12:79–115.

Torrence, R. Editor. 1989. *Time, energy and stone tools.* Cambridge, UK: Cambridge University Press.

Trigger, B. C. 1999. "Master and servant: A conference overview," in *Taming the taxonomy.* Edited by R. F. Williamson and C. M. Watts, pp. 303–322. Toronto: Eastendbooks.

Tugby, D. J. 1958. A Typological Analysis of Axes and Choppers from Southeast Australia. *American Antiquity* 24:24–33.

Tylor, E. B. 1929 [1871]. *Primitive Culture.* London: J. Murray.

Vallin, L., B. Masson, and J.-P. Caspar. 2001. Taphonomy at Hermies, France: A Mousterian knapping site in a Loessic context. *Journal of Field Archaeology* 28:419–436.

Van Buren, G. E. 1974. *Arrowheads and projectile points.* Garden Grove, CA: Arrowhead.

van der Leeuw, S. E. 2000. "Making tools from stone and clay," in *Australian archaeologist: Collected papers in honour of Jim Allen.* Edited by P. Anderson and T. Murray. Canberra: Australian National University Press.

van der Leeuw, S. E., and C. L. Redman. 2002. Placing archaeology at the center of socio-natural studies. *American Antiquity* 67:597–605.

VanPool, T. L. 2001. "Style, function an variation: Identifying the evolutionary importance of traits in the archaeological record," in *Style and function: Conceptual issues in evolutionary archaeology.* Edited by T. D. Hurt and G. F. M. Rakita, pp. 117–140. Westport, CT: Bergin & Garvey.

Vierra, B. J. 1995. *Subsistence and stone tool technology: An old world perspective,* vol. 47. *Arizona State University Anthropological Research Papers.* Tempe: Arizona State University.

Voorrips, A. 1982. "Mambrino's helmet: A framework for structuring archaeological data," in *Essays on archaeological typology.* Edited by R. Whallon and J. A. Brown. Evanston, IL: Center for American Archaeology Press.

Voss, J. A. 1977. The Barnes site: Functional and stylistic variability in a small Paleo-Indian assemblage. *Midcontinental Journal of Archaeology* 2:253–305.

Washburn, D. K., and D. W. Crowe. 1988. *Symmetries of culture: Theory and practice of plane pattern analysis.* Seattle: University of Washington Press.

Waterbolk, H. T., and W. van Zeist. 1967. Preliminary report on the Neolithic bog settlement of Niederwil. *Palaeohistoria* 12:559–580.

———. 1978. *Niederwil, eine Siedlung der Pfyner Kultur.* Vol. Band I: De Grabungen. Band II: Beilagen. Bern: Paul Haupt.

Weisstein, E. W. 2006. Bell number [Electronic Version]. Retrieved July 4, 2006 from http://mathworld.wolfram.com/BellNumber.html.

Welbourn, A. 1984. "Endo ceramics and power strategies," in *Ideology, power and prehistory.* Edited by D. Miller and C. Tilley, pp. 17–24. Cambridge, UK: Cambridge University Press.

Whallon, R. 1972. A new approach to pottery typology. *American Antiquity* 37:13–33.

———. 1982. "Variables and dimensions: The critical step in quantitative typology," in *Essays in archaeological typology.* Edited by R. Whallon and J. A. Brown, pp. 127–161. Evanston, IL: Center for American Archaeology Press.

———. 1990. "Defining structure in clusterming dendrograms with multilevel clusterming," in *New tools from mathematical archaeology.* Edited by A. Voorrips and B. Ottaway, pp. 1–14. Cracow: Polish Academy of Sciences. Commission on Archaeology.

Wheat, J. B., J. C. Gifford, and W. W. Wasley. 1958. Ceramic variety, type cluster, and ceramic system in Southwestern pottery analysis. *American Antiquity* 24:34–47.

White, P. J., N. Modjeska, and I. Hipuya. 1977. "Group definitions and mental templates: An ethnographic experiment," in *Stone tools as cultural markers: Change, evolution and complexity. Prehistory and Material Culture Series No. 12.*

Edited by R. V. S. Wright, pp. 380–390. Canberra: Australian Institute of Aboriginal Studies.
Whiteford, A. H. 1947. Description for artifact analysis. *American Antiquity* 12:226–239.
Whittaker, J. C., D. Caulkins, and K. A. Kamp. 1998. Evaluating consistency in typology and classification. *Journal of Archaeological Method and Theory* 5:129–164.
Wiessner, P. 1983. Kalahari san projectile points. *American Antiquity* 48:253–276.
———. 1985. Style or isochrestic variation? A reply to Sackett. *American Antiquity* 50:160–166.
Williams, W. T., and J. M. Lambert. 1959. Multivariate methods in plant ecology I: Association analysis in plant communities. *Journal of Ecology* 47:83–107.
———. 1960. Multivariate methods in plant ecology I: The use of an electronic digital computer for association analysis. *Journal of Ecology* 48:698–710.
Wilmsen, E. N., and F. H. H. Roberts, Jr. 1978. *Lindenmeier. 1934–1974*. Washington, DC: Smithsonian Institution Press.
Wilson, C. D., and E. Blinman. 1995. "Changing specialization of white ware manufacture in the northern San Juan region," in *Ceramic production in the American Southwest*. Edited by B. J. Mills and P. L. Crown, pp. 63–87. Tucson: University of Arizona Press.
Wilson, C. D., E. Blinman, J. N. Skibo, and M. B. Schiffer. 1996. "Designing Southwestern pottery: A technological and experimental approach," in *Interpreting southwestern diversity: Underlying principles and overarching patterns, Anthropological Research Papers No. 48*. Edited by P. R. Fish and J. J. Reid, pp. 249–256. Tempe: Arizona State University.
Wilson, T. 1899a. "Arrowheads, spearheads and knives of prehistoric times," in *United States National Museum, Annual Report (1897), Part I*, pp. 811–988.
———. 1899b. *Chipped stone classifications*.
Wobst, H. M. 1977. "Stylistic behaviour and information exchange," in *For the director: Research essays in honor of James B. Griffin*, vol. 61, *Anthropological Papers*. Edited by C. E. Cleland, pp. 317–342. Ann Arbor: University of Michigan Museum of Anthropology.
Wylie, A. 1995. "An expanded behavioral archaeology: Transformation and redefinition," in *Expanding archaeology*. Edited by J. N. Skibo, W. H. Walker, and A. E. Nielsen. Salt Lake City: University of Utah Press.
———. 2002. *Thinking from things: Essays in the philosophy of archaeology*. Berkeley: University of California Press.
Wynn, T., and F. Tierson. 1990. Regional comparison of the shapes of later Acheulean handaxes. *American Anthropologist* 92:73–84.
Young, D. E., and R. Bonnichsen. 1985. "Cognition, behavior, and material culture," in *Stone tool analysis: Essays in honor of Don H. Crabtree*. Edited by M. G. Plew, J. C. Woods, and M. G. Pavesic, pp. 91–131. Albuquerque: University of New Mexico Press.
Zahavi, A., and A. Zahavi. 1997. *The handicap principle: A missing piece in Darwin's puzzle*. Oxford: Oxford University Press.
Zeaneh, D. W., and R. G. Elston. 2001. Testing a simply hypothesis concerning the resilience of dart point styles to hafting element repair. *Journal of California and Great Basin Anthropology* 23:93–12.

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About the Author

Dwight W. Read is a Professor of Anthropology and of Statistics at UCLA, where he received his Ph.D in mathematics. He is also one of the founding faculty and Chair for the newly established Interdegree Program in Human Complex systems at UCLA. Read is a four field anthropologist with research work that focuses on statistical modeling of hominid evolution, theory and method of artifact classification, and formal/mathematical representation of cultural constructs such as kinship terminologies. In addition to numerous refereed articles in print, he was co-editor (with Fred Plog and James Hill) of *Chevelon Archaeological Research Project 1971–72* and has edited theme issues of *Journal of Quantitative Anthropology*, *Journal of Artificial Societies and Social Simulation*, and *Cybernetics and Systems*. Read developed a major computer program (*Kinship Algebraic Expert System*, or *KAES*) that constructs a formal (algebraic) model of the logic underlying the structure of a kinship terminology and implements that logic in the form of correctly predicted genealogical definitions of kin terms. He has been the recipient of several National Science Foundation grants and other research funding.